

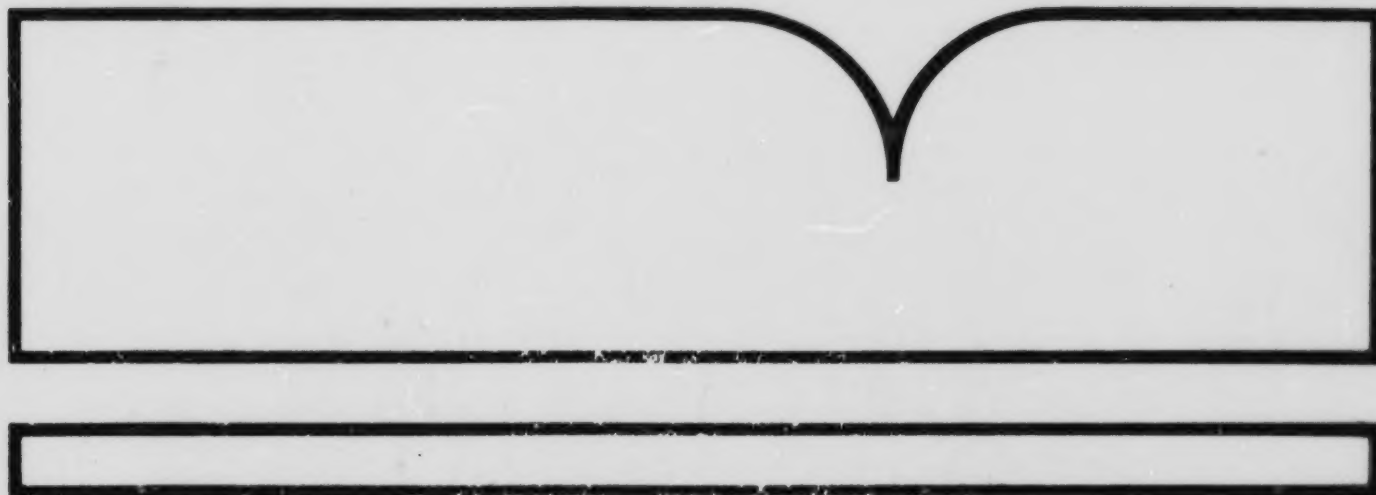
Operation and Maintenance of Selected
Ozone and Ultraviolet Disinfection Systems

Weston (Roy F.), Inc., West Chester, PA

Prepared for

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OPERATION AND MAINTENANCE
OF
SELECTED OZONE AND ULTRAVIOLET DISINFECTION SYSTEMS

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FOREWORD

The U. S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This report discusses various factors that affect the operation and maintenance of ozone and ultraviolet disinfection systems. The information presented is intended to provide feedback to the technology development community, design engineers, municipalities, and state and local agencies to promote improved POTW design, construction, performance, and system reliability.

ABSTRACT

This report details one of EPA's efforts to compile and promulgate design and operational information concerning the use of ozone disinfection or UV light disinfection for wastewater effluents. During the study, onsite evaluations were conducted at seven municipal wastewater treatment plants that are using or have used ozone, five water treatment plants using ozone for disinfection and/or odor control, and three municipal wastewater treatment plants that are using or have used ultraviolet light systems for disinfection of the treated effluent. During these plants visits operating data were reviewed, operational practices observed, and operating personnel were interviewed in order to establish O&M causative factors relating to poor and efficient process performance. The typical O&M problems have been listed and the recommended remedial actions necessary to correct those problems are presented in the paper.

This report was submitted in fulfillment of Contract No. 68-03-3019 by Roy F. Weston, Inc., under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period June 1982 to September 1983.

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SECTION 1

INTRODUCTION

1.1 PROJECT SCOPE AND OBJECTIVES

Alternatives to chlorine disinfection of municipal wastewater have been given increased attention in recent years. Two alternative approaches that have generated particular interest are ozone and ultraviolet (UV) light disinfection. This project was initiated to identify operation and maintenance factors affecting the performance of ozone and UV disinfection systems. The study was part of the U.S. Environmental Protection Agency (U.S. EPA) efforts to compile and promulgate design and operational information on ozone and UV light disinfection.

The objective of the study was to determine, analyze, and set priorities for those O&M factors that affect the operational efficiencies of ozone and UV disinfection systems. During the study, onsite evaluations were conducted at 10 municipal wastewater treatment plants and 5 municipal water treatment plants that use ozonation or UV irradiation for disinfection or taste and odor control, or both. During these plant visits, operating personnel were interviewed, operational practices were observed, and operating data were reviewed to identify O&M factors related to poor and efficient process performance. The information compiled was documented in individual plant evaluation reports (see appendix) and is summarized in this final project report. The report presents the O&M problems encountered, conclusions drawn concerning their cause, and recommendations made toward their resolution.

1.2 STUDY METHODOLOGY

The study methodology used to accomplish the project goals described above is shown in Figure 1-1. Initially, existing data concerning the operation of ozone and UV disinfection systems and descriptive information about the 15 treatment plants to be evaluated were collected and reviewed. Simultaneously, a preliminary telephone survey of the treatment plants was conducted to gather design information and schedule plant trips. Site visits were subsequently made to observe equipment operation, review plant operating data, and identify those O&M factors that affect the performance of ozone and UV disinfection systems. Following

completion of the field trips, the data collected were analyzed, and cause and effect relationships were formulated between the identified O&M factors and system efficiencies being achieved.

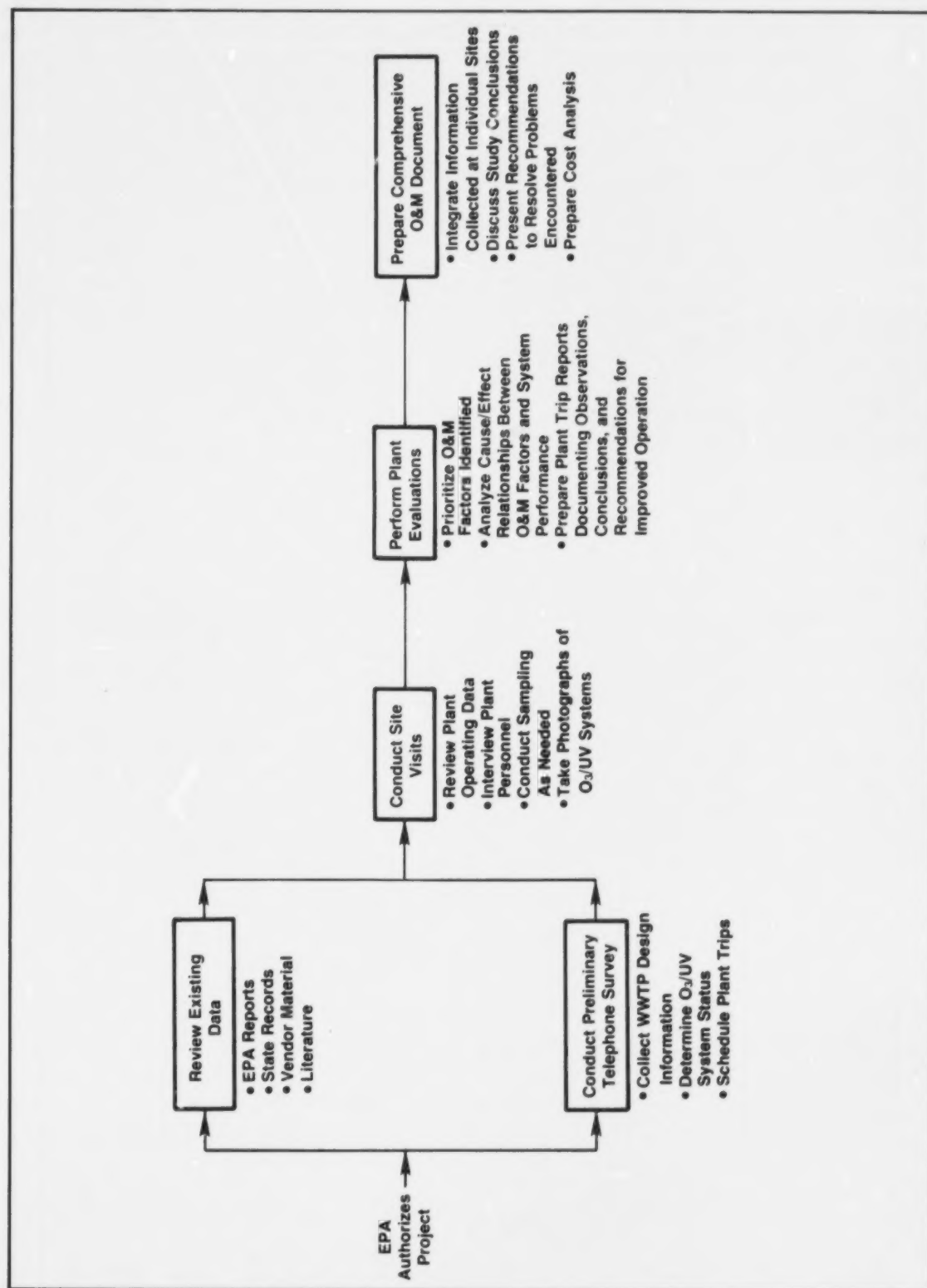


FIGURE 1-1 PROJECT METHODOLOGY

SECTION 2

CONCLUSIONS

2.1 OZONE DISINFECTION

Most of the operational and maintenance problems experienced with the ozone disinfection systems surveyed were site-specific and not prevalent problems that repeatedly occurred at all the sites visited. The most common problems that were identified included:

- Inefficient ozone destruction in the destruct unit.
- Ozone generator cell failure.
- Ozone leakage from generator.
- Inadequate air drying in the inlet air desiccant dryer.
- Improper sealing of the ozone contact tank.
- Malfunctioning of the ozone concentration monitors.

Detailed descriptions of the problems encountered are presented in Section 6, and the individual plant trip reports are included in the appendix.

2.2 ULTRAVIOLET DISINFECTION

Limited information was available concerning the operation of UV disinfection systems. But as with ozone disinfection, most of the O&M problems identified were site-specific and not widespread occurrences. The specific problems encountered are summarized in Section 6 and discussed in detail in the individual plant trip reports presented in the appendix.

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SECTION 3

RECOMMENDATIONS

Before an ozone or UV disinfection system is designed, the problems listed in Section 6 and the associated corrective measures described in Section 7 should be reviewed to minimize system O&M problems.

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SECTION 4

OZONE AND UV DISINFECTION PROCESS DESCRIPTIONS

4.1 OZONE DISINFECTION

Ozone is produced commercially from dry air or oxygen by means of the corona discharge of high voltage (4,000 to 30,000 volts) electricity. Ozone is a powerful oxidizing agent (only fluorine has a more electronegative oxidation potential) and is extremely corrosive. The free radicals HO_2 and HO that form when ozone decomposes in aqueous solutions have great oxidizing power and are believed to be the principal reacting species. The potent germicidal properties of ozone have been attributed to its high oxidation potential.

The key elements of an ozone system include: pretreatment of the air supply (unless oxygen is used, in which case pretreatment is generally not needed); generation of ozone; transfer of ozone to the wastewater flow in a contact tank; and destruction of ozone off-gases collected in the contact tank.

The three basic flow schemes that can be used to generate ozone include:

- Once-through oxygen.
- Oxygen recycle.
- Once-through air.

A flow diagram illustrating these three ozone generation schemes is shown in Figure 4-1. The process flow scheme for the once-through oxygen system is shown as path G-D-E-F-H in Figure 4-1. Oxygen is produced on-site by a cryogenic or pressure-swing adsorption process and is fed to the ozone generator. The ozone produced is then diffused into the wastewater flow inside an ozone contact tank. The off-gas from the ozone contact tank is passed through an ozone-destruct unit where the ozone is reconverted to oxygen. The oxygen-rich discharge from the destruct unit is then fed to an oxygen-activated sludge process. The oxygen recycle flow scheme is shown as path G-D-E-F-A-B-C in Figure 4-1. In this flow scheme the oxygen-rich off-gas is recycled

through a compressor and refrigerant dryer for cleaning and drying before returning to the ozone generator. Oxygen loss from the recycle loop by ozone conversion and dissolution in the wastewater is made up from the oxygen source. In addition, recycled gas is purged and make-up oxygen is added to maintain a sufficient oxygen concentration in the recycle loop. This purging procedure is necessary because of oxygen dilution by nitrogen gas, which is stripped in the ozone contact chambers, and carbon dioxide produced by ozone oxidation of organic matter. The once-through air flow scheme is depicted as path A-B-C-D-E-F-I in Figure 4-1. In this flow scheme the discharge from the destruct unit is vented to the atmosphere.

Currently, electrical production is the only practical and economical method available for commercial ozone generation. This process involves the passage of air or oxygen between electrodes, across which an alternating high-voltage potential is maintained. To ensure the most efficient conversion of oxygen into ozone, a uniform blue-violet glow discharge is maintained throughout the gas. The glow discharge is created by inserting a dielectric material between the electrodes, which causes the glow to spread uniformly and prevents breakdown into an arc discharge. Ozone generation via the corona discharge method is very inefficient and only about 10 percent of the energy applied results in the production of ozone. The largest portion of the energy loss can be attributed to heat generation. The remainder is lost as light and sound. The decomposition of ozone back to oxygen is greatly accelerated with increasing temperature; therefore, all high concentration ozonators must include a system for heat removal.

The air supply to the ozonator must be filtered to ensure the absence of dust, and it must be very dry. For efficient production of ozone, the water in the air must first be removed so that the dew point is not higher than -46°C (-50°F). When water vapor concentrations are higher than this, not only is ozone production adversely affected, but also oxides of nitrogen are produced that both accelerate the decomposition of ozone as well as combine with water vapor to form nitric acid, causing corrosion problems. A dew point of -46°C (-50°F) can be achieved via silica gel or activated alumina desiccation. This approach is often used in small installations. In larger plants, desiccation is generally preceded by refrigeration drying.

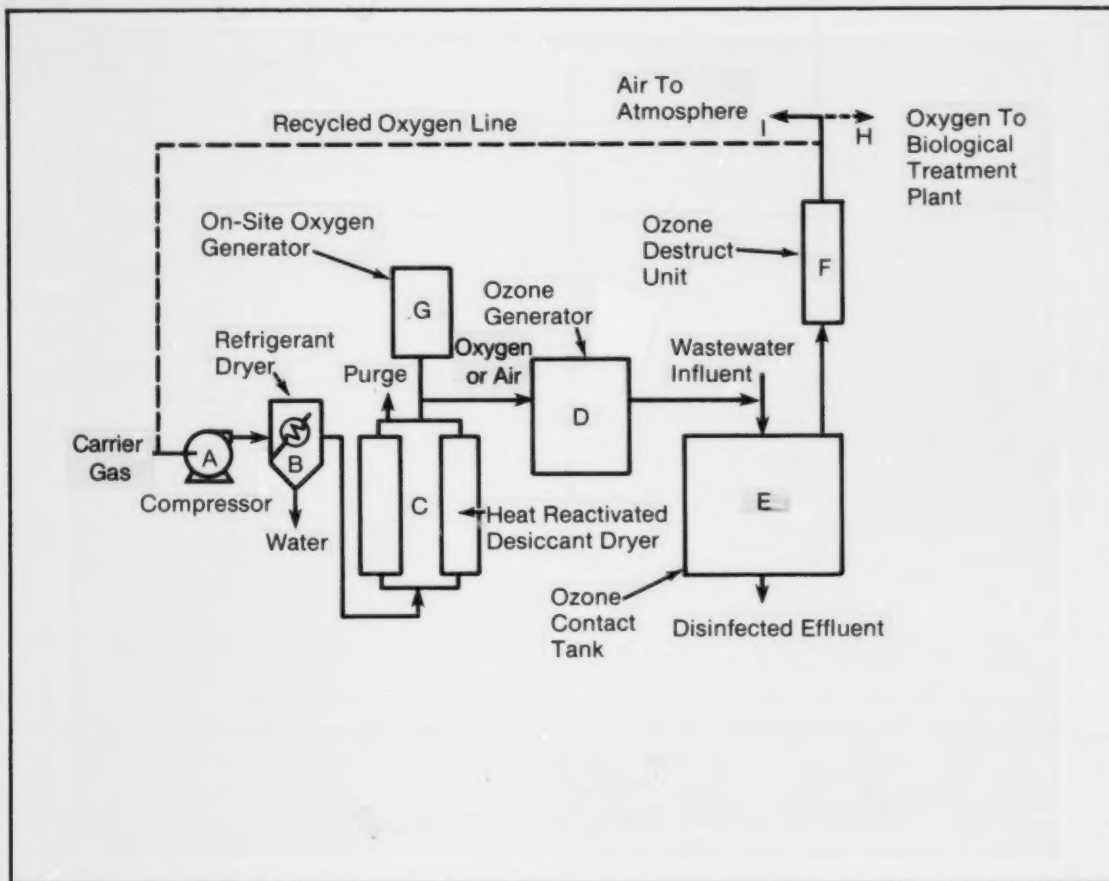


FIGURE 4-1 DIAGRAM OF VARIOUS OZONE DISINFECTION FLOW SCHEMES*

*Source - White, G.C., "Disinfection of Wastewater and Water for Reuse" Van Nostrand Reinhold Environmental Engineering Series, 1978. (Courtesy Union Carbide Co.).

When using oxygen for the production of ozone, refrigeration and/or desiccation drying is normally not required because oxygen is produced at low temperatures and is initially dry. However, if oxygen recycling is employed in order to conserve oxygen use, then drying equipment similar to that used for air preparation is required.

There are three basic types of corona-discharge ozone generators:

- The Otto plate.
- The tube type.
- The Lowther plate.

A sketch of an Otto plate generator, which is the oldest type, is shown in Figure 4-2. Air is blown into the ozonator and enters the discharge gap where ozone is formed. The ozonized air is drawn through a manifold pipe formed by a hole cut in the center of each of the electrodes and dielectrics. One of the inherent disadvantages of the Otto type generator is that only low pressure air can be blown into the ozonator discharge gap.

The tube-type generator (see Figure 4-2) is composed of numerous stainless steel, outer electrode tubes fastened in place with stainless steel spacers. These outer ground electrodes are surrounded by cooling water. Centered inside the stainless steel tubes are tubular glass dielectrics with inner surfaces that are coated with a conductor that acts as the second electrode. The electrodes are arranged in parallel and are enclosed in a gas-tight vessel. Either air or oxygen is fed into the unit at one end and passes through the discharge gap between the outer ground electrode and the inner glass dielectric. Ozone is subsequently formed and collected at the end of the generator.

The Lowther plate generator (see Figure 4-2), although a plate-type unit, is significantly different from an Otto plate generator. The Lowther generator is air cooled, and can use either air or oxygen feed. The basic unit is a gas-tight assembly made up of an aluminum heat dissipator, a steel electrode coated with a ceramic dielectric, a glass spacer to set the discharge gap, a second ceramic-coated steel electrode with a gas (oxygen or air) inlet, and an ozone outlet through a second aluminum dissipator. These components are sandwiched together in a frame and manifolded for oxygen and ozone flow. A cooling fan circulates ambient air across the heat dissipators in order to maintain the proper operating temperature within the generator.

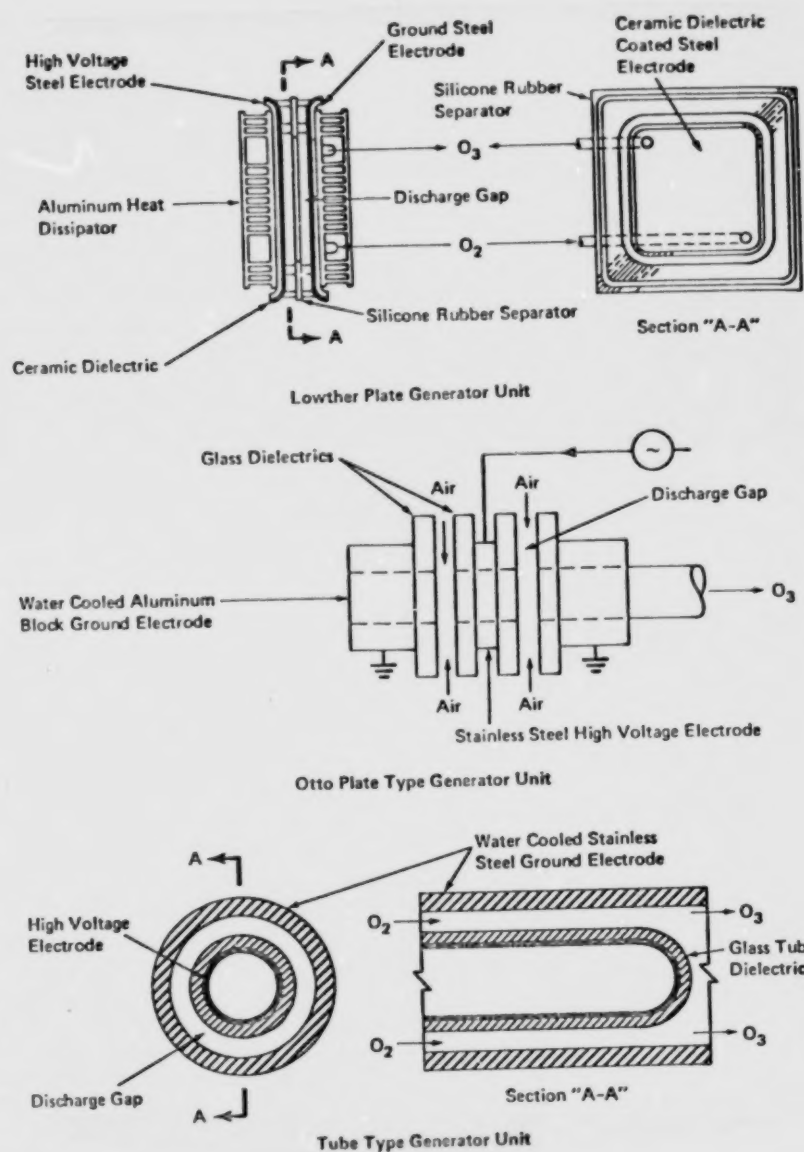


FIGURE 4-2 TYPICAL COMMERCIAL OZONE GENERATORS*

*Source - Evans, F.L., III, "Ozone in Water and Wastewater Treatment," Ann Arbor Science, Ann Arbor, MI, 1972.

Operating characteristics and power requirements for these three different types of generators are compared in Table 4-1.

The solubility of ozone in water is a limiting factor that greatly affects the ozonation process. As a comparison, chlorine is 12 times more soluble than ozone. Due to its low solubility, ozone contact tanks must be sealed so any undissolved ozone can be collected and recirculated or reconverted to oxygen in an ozone-destruct unit. Ozone can be reconverted to oxygen via a thermal and/or a catalytic ozone-destruct unit. Since ozone is a toxic gas, the ozone concentration in the destructor exit gas should be less than 0.1 ppm by volume. In ozone generation systems that use air as the feed gas, exit gas from the destructor unit is discharged to the atmosphere. At pure oxygen-activated sludge plants, the oxygen-laden destructor exit gas is returned to the treatment process and reused.

4.2 ULTRAVIOLET DISINFECTION PROCESS DESCRIPTION

The radiation energy of ultraviolet (UV) light can be used to disinfect wastewater. In order to be effective, the electromagnetic waves of UV radiation must actually strike the organism. In the process, some of the radiation energy is absorbed by the organism and some by other constituents in the medium surrounding the organisms. The germicidal effect of UV energy is thought to be associated principally with its absorption by nucleic acids essential to the replication of cells. Energy dissipation by excitation, which causes disruption of the nucleic acid molecules that are vital to both bacteria and viruses, appears to produce a progressively lethal biochemical change. UV treatment does not chemically alter water since nothing is added except energy, which produces heat resulting in a negligible temperature rise in the treated water.

Table 4-1

Typical Ozone Generator
Operating Characteristics*

Parameter	Generator Type		
	Otto	Tube	Lowther
Feed gas	Air	Air or Oxygen	Air or Oxygen
Dew point of feed, °C	-51	-51	-40
Cooling	Water	Water	Air
Pressure, kg/m ²	0	2,109-10,546	703-8,437
Discharge gap, cm	0.318	0.254	0.127
Voltage, kv. peak	7.5-20	15-19	8-10
Frequency, Hz	50-500	60	2,000
Dielectric thickness, cm	0.30-0.48	0.25	0.05
Power required, air feed (kwh/kg)	22.5	16.5-22.0	14.9-19.3
Power required, oxygen feed (kwh/kg)	---	8.25-11.01	5.5-7.7

*Source - Evans, F. L., III, "Ozone in Water and Wastewater Treatment," Ann Arbor Science, Ann Arbor, MI, 1972.

Most species of microorganisms can be killed by UV radiation with a wavelength in the range of 250 to 260 nanometers. Commercial UV disinfection units attempt to provide a high percentage (85 to 90 percent) of radiation at 254 nm, which is the optimal germicidal wavelength. Most commercial units used for municipal wastewater disinfection utilize a water-tight vessel containing quartz sleeved, mercury vapor lamps. The wastewater is exposed to UV radiation as it flows through the network of quartz sleeves. An effluent overflow weir is used to maintain a minimum liquid level in the unit and ensure complete submergence of the UV lamps. At least one manufacturer, however, uses teflon tubes to convey the wastewater through the radiation chamber, which contains UV lamps positioned in the air space around the teflon tubes. Figure 4-3 illustrates both types of units.

The disinfection efficiency of a UV system is primarily dependent on the UV dose (normally defined as microwatt seconds/square centimeter) applied. The required dose will vary as effluent quality varies. Determination of the actual dose being delivered involves defining the hydraulic detention time in the unit throughout the expected range of flows, and defining the average intensity of the UV radiation in the unit in microwatts/square centimeter. These two parameters are unit-specific. The average intensity to which the wastewater flow is exposed is a function of the total number of lamps, their types, size, and the geometry of the lamp placement in relation to the wastewater flow.

UV units must be routinely cleaned to prevent the buildup of coatings on component surfaces in contact with the wastewater. Such coatings will reduce UV intensity and adversely affect the efficiency of the UV disinfection process. Older UV units require periodic manual cleaning with chemical cleaners. Newer models are equipped with automatic mechanical or ultrasonic cleaning apparatus.

One characteristic of UV units is that residual disinfection is not provided. If the microorganisms are sublethally injured as they pass through the UV unit, they can be photoreactivated when exposed to visible light after passing through the UV unit.

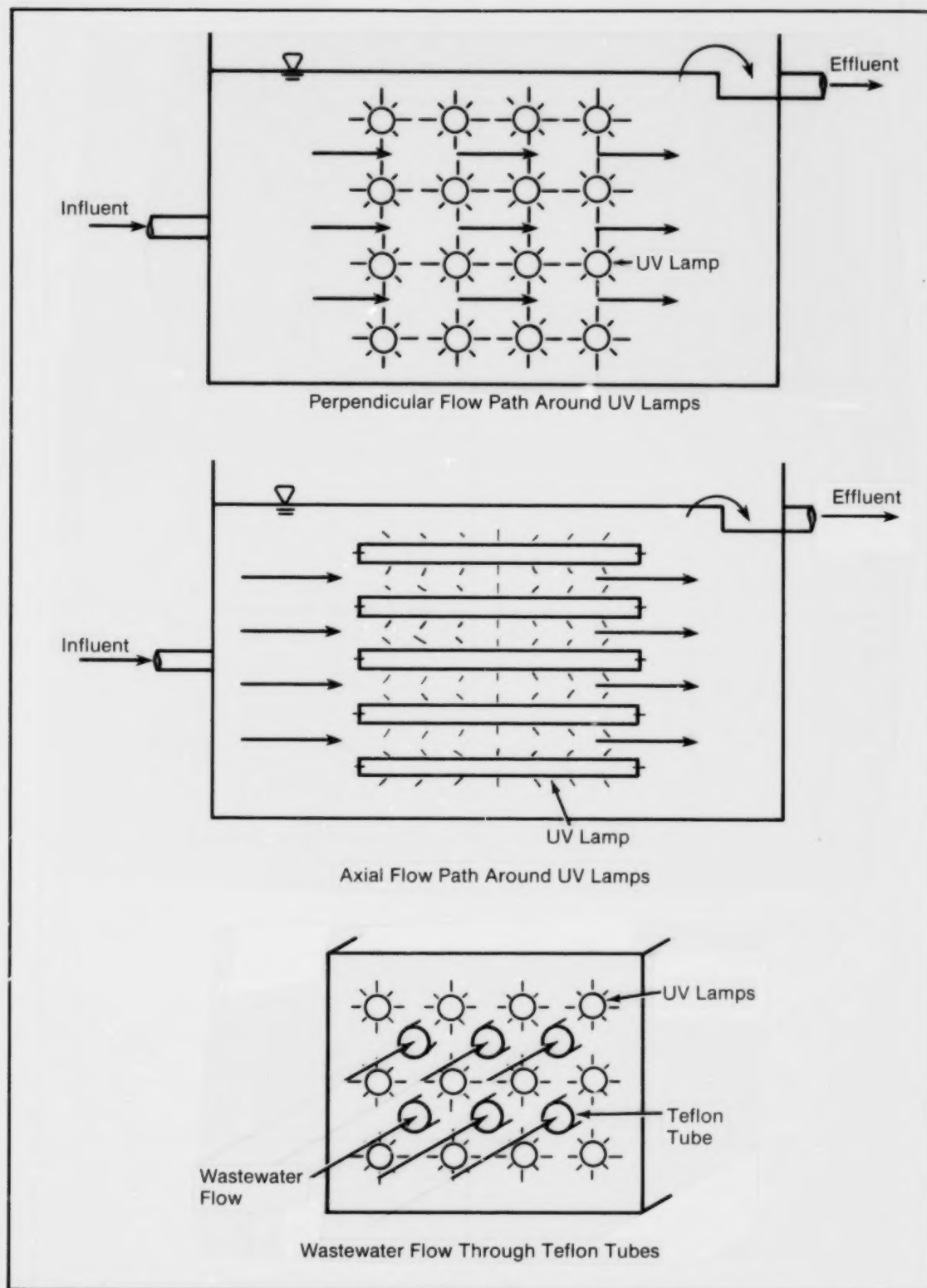


FIGURE 4-3 TYPICAL UV DISINFECTION EQUIPMENT FLOW ARRANGEMENTS

SECTION 5

PLANT EVALUATIONS

5.1 SITES VISITED

During the study, 15 sites were visited. These included 10 municipal wastewater treatment plants and 5 municipal water filtration plants. Twelve of the facilities utilized ozone systems for disinfection and/or taste or odor control, and three of the plants utilized UV disinfection systems. The plants visited are listed in Table 5-1.

It is noted that initially 18 wastewater treatment plants that use ozone for effluent disinfection were considered for evaluation site visits. However, a preliminary telephone survey indicated the status of their ozone system was as follows:

Ozone System Status	No. of Plants
Operational	7
Abandoned	7
Periodically Used	2
Not Started-Up Yet	<u>2</u>
Total	18

Therefore, in order to supplement the data base for ozone systems, five water treatment plants that use ozone for taste and odor control were also visited.

5.2 PLANT DESCRIPTIONS

5.2.1 Plant Trip Reports

Following each site visit, a detailed trip report was prepared. These trip reports included general descriptive information about the treatment plant and specific information concerning the disinfection equipment utilized, system operational control

procedures, start-up and operational problems, operations and maintenance staff, maintenance requirements, and operations and maintenance costs (when available). These trip reports are included in the appendix of this report. The trip reports can be referred to for specific information concerning the individual plants surveyed. A summary of the information compiled during the site survey phase of the project is presented in the following sections.

Table 5-1

Listing of Ozone and UV Plants Surveyed

Plant No.	Plant*	Location	Disinfection System	
			Ozone	UV
1	Rocky River Regional WWTP	Concord, NC	X	
2	Upper Thompson Sanitation District WWTP	Estes Park, CO	X	
3	Frankfort WWTP	Frankfort, KY	X	
4	Southwest WWTP	Springfield, MO	X	
5	Brookings WWTP	Brookings, SD	X	
6	Murfreesboro WWTP	Murfreesboro, TN	X	
7	Madisonville WWTP	Madisonville, KY	X	
8	Monroe WTP	Monroe, MI	X	
9	Bay Metro WTP	Bay City, MI	X	
10	Charles J. Des Baillets WTP	City of La Salle, CAN	X	
11	Pierrefonds WTP	City of Pierrefonds, CAN	X	
12	Sherbrooke WTP	Sherbrooke, CAN	X	
13	Sents Creek WWTP	Pella, IO		X
14	Sanford WWTP	Sanford, MA		X
15	Hatfield WWTP	Hatfield, AR		X

*WWTP - Wastewater Treatment Plant.
WTP - Water Treatment Plant.

5.2.2 Ozone Plants

Descriptive information about the plants that used ozone systems, and design data concerning their systems, are presented in Tables 5-2 and 5-3, respectively. It can be seen that plant hydraulic capacities ranged from 5,677 m³/d to 1,135,530 m³/d, and ozone system capacities ranged from 69 kg per day to 3,479 kg per day. It is also noted that 50 percent of the wastewater treatment plants contacted utilized a pure oxygen activated sludge process, which included second stage nitrification. Over all, four of the ozone plants used oxygen as the ozone carrier gas, and eight used air as the carrier gas. Most of the ozone facilities surveyed had only been on-line for three years or less.

5.2.3 UV Plants

Descriptive information about the three plants surveyed that utilize UV disinfection, and design data concerning the disinfection systems, are presented in Tables 5-4 and 5-5, respectively. The hydraulic capacities of the plants visited ranged from 264 m³/d to 26,500 m³/d. It is also noted that all three plants have been on-line only two years or less.

5.3 OZONE AND UV SYSTEMS PERFORMANCE

Information concerning operational parameters and disinfection performance for the ozone and UV plants surveyed is presented in Tables 5-6 and 5-7, respectively. It can be seen that disinfection efficiencies for the ozone plants varied considerably.

5.4 O&M COSTS

Annual cost information for those ozone plants surveyed that had compiled historical cost data is presented in Table 5-8. Detailed cost breakdowns for the individual plants are included in the plant trip reports presented in the appendix. The average ozone production cost for the 12 plants surveyed is approximately \$4.20/kg (\$1.90/lb) of ozone generated and ranges from \$0.63/kg (\$0.28/lb) to \$9.03/kg (\$4.08/lb). Assumptions made in estimating the annual cost presented in Table 5-8 are summarized in the individual plant trip reports included in the appendix.

Very little maintenance and cost data were available for the UV plants surveyed during this project. The Hatfield, Arkansas wastewater treatment plant reported a UV disinfection operating cost of approximately \$0.18/1,000 gallons treated. Sufficient data were not available at the other two UV sites to formulate

Table 5-2
Ozone Plants - Plant Descriptions

Plant No.	O ₃ Start-Up Date mo/yr	Operational (O) or Shut-Down Date (mo/yr)	Type Plant*	Average Flow		Eff. Quality	
				Design m ³ /d (mgd)	Current m ³ /d (mgd)	BOD mg/L	SS mg/L
1	10/80	O	O ₂ - A.S. + Nit.	90,840 (24.0)	45,420 (12.0)	20	30
2	9/76	6/80	A.S.	5,677 (1.5)	2,271 (0.60)	3	2
3	2/81	O	O.D.	16,276 (4.3)	17,033 (4.5)	20	20
4	8/78	O	O ₂ - A.S. + Nit.	151,400 (40.0)	113,550 (30.0)	2	2
5	4/81	7/81	RBC + A.S.	11,355 (3.0)	8,327 (2.2)	10	12
6	2/81	**	O ₂ - A.S. + Nit.	30,280 (8.0)	15,897 (4.2)	9	8
7	4/81	6/81	O ₂ - A.S. + Nit.	17,033 (4.5)	14,762 (3.9)	3	3
8	2/79	O	WTP	68,133 (18.0)	26,496 (7.0)	---	---
9	9/79	O	WTP	151,404 (40.0)	37,851 (10.0)	---	---
10	2/79	O	WTP	1,135,530 (300.0)	798,656 (211.0)	---	---
11	6/76	O	WTP	94,600 (25.0)	56,800 (15.0)	---	---
12	8/77	O	WTP	113,500 (30.0)	58,700 (15.5)	---	---

*RBC - Rotating Biological Contactor

A.S. - Activated Sludge

O₂-A.S. - Pure Oxygen Activated Sludge

Nit. - Nitrification

O.D. - Oxidation Ditch

WTP - Water Treatment Plant

**Continuous operation since mid-1981 has not been possible.

Table 5-3

Ozone Plants - Ozone System Data

Plant No.	Number of Generators	Generator Manufacturer	Total Capacity kg/d (lb/d)	Carrier Gas	Actual O ₃ Transfer Efficiency**
1	17	Union Carbide	2,082 (4,590)	O ₂	50%
2*	2	Welsbach	69 (152)	Air	50%
3	3	Emery	782 (1,725)	Air	60%
4	13	Union Carbide	1,562 (3,445)	O ₂	95%
5*	2	Emery	113 (250)	Air	67%
6*	3	Emery	381 (840)	O ₂	84%
7*	3	Union Carbide	571 (1,260)	O ₂	---
8	2	PCI	204 (450)	Air	---
9	4	Welsbach	453 (1,000)	Air	85%
10	6	Trailigaz	3,479 (7,680)	Air	80%
11	4	Trailigaz	204 (450)	Air	---
12	4	Degremont	227 (500)	Air	94%

*Not in operation.

$$**\text{Transfer efficiency} = \frac{O_3 \text{ (in)} - O_3 \text{ (out)}}{O_3 \text{ (in)}}$$

Table 5-4

Ultraviolet Plants - Plant Descriptions

Plant No.	Start- Up Date (mo/yr)	Shut- Down Date (mo/yr)	Type Plant*	Average Flow		Eff. Quality	
				Design m ³ /d (mgd)	Current m ³ /d (mgd)	BOD mg/L	SS mg/L
13	11/81	---	A.S.	26,500 (7.0)	5,700 (1.5)	15	15
14	6/81	8/81	A.L.	13,600 (3.6)	9,500 (2.5)	2	2
15	3/80	5/81	F.L., O.F.	264 (0.07)	113 (0.03)	10	15

*A.S. - Activated Sludge
 A.L. - Aerated Lagoon
 F.L. - Facultative Lagoon
 O.F. - Overland Flow

Table 5-5

Ultraviolet Plants - UV System Data

Plant No.	UV Manufacturer	No. of Sections	Total Number of Lamps	Lamp Length, m (in.)	Cleaning Mechanisms	Flow/Unit m ³ /d (mgd)	Arc Length Per Unit of Flow m/m ³ /d (in./gpm)
13	Pure Water Systems	6	392	1.5 (60)	Mechanical Wiper	2,839 (0.75)	44,451 (4.6)
14	Aquafine	4	128	1.5 (60)	Mechanical Wiper	4,163 (1.25)	28,990 (330)
15	Ultraviolet Technology, Inc.	3	48	0.8 (30)	Chemical Detergent	113 (0.03)	289,902 (30)

Table 5-6

Ozone System Performance

Plant No.	Operational Mode		Contact Time, Minutes		Ozone Dosage Applied, mg/L		Average Fecal Coliform Count/100 ml	
	Auto.	Manual	Actual	Design	Actual	Design	Inf.	Eff.
1	X		14	14	14	14	---	1,000
2*		X	14	14	9	6	18,000	12
3	X		48	48	4	3	350,000	200
4		X	20	20	4	4	---	1
5*	X		60	30	4	10	30,000	3,000
6*		X	40	30	7	6	---	100
7*		X	15	15	6	6	20,000	100
8	X		25	10	1.5	3	O ₃ used for taste and odor control	
9	X		45	30	3	2	O ₃ used for taste and odor control	
10	X		5	5	2.2	2.2	O ₃ used for taste and odor control	
11		X	4	4	3.5	3.5	O ₃ used for taste and odor control	
12		X	4	4	2	2	O ₃ used for taste and odor control	

*Not in operation.

Table 5-7
Ultraviolet Plants - UV System Performance

Plant No.	Contact Time, Seconds	Dosage uw-sec/cm ²	Fecal Coliform Count/100 ml	
			Inf.	Eff.
13	3.5	---	---	70
14	1.5	30,000	5	1
15	60	---	---	70

Table 5-8

Ozone Systems - O&M Cost Summary

Plant No.	Plant	Current Average Flow m ³ /d (mgd)	Ozone Production kg/day (lb/day)	Ozone Production Cost	
				¢/kg (¢/lb)	¢/m ³ (¢/1,000 gal)
1	Rocky River WWTP	45,420 (12.0)	1,010 (2,227)	63 (28)	1.4 (5.2)
2	Upper Thompson WWTP*	2,271 (0.6)	22 (49)	602 (272)	5.8 (22)
3	Frankfort WWTP	17,033 (4.5)	85 (187)	382 (173)	1.9 (7.1)
5	Brookings WWTP*	8,327 (2.2)	27 (60)	488 (221)	1.2 (5.9)
8	Monroe WTP	26,496 (7.0)	36 (79)	903 (408)	1.2 (4.8)
9	Bay Metro WTP	37,851 (10.0)	97 (214)	575 (261)	1.5 (5.8)
10	Charles J. Des Balleys WTP	798,656 (211)	1,740 (3,836)	191 (86)	0.4 (1.4)
11	Pierrefonds WTP	56,800 (15)	135 (298)	342 (154)	0.8 (2.9)
12	Sherbrooke WTP	58,700 (15.5)	113 (250)	259 (116)	0.5 (2.0)

*Not in operation.

annual operating costs for these two facilities. Minimal information was available for the Sanford, Maine plant because their UV system was only on-line approximately three months before being shut down. Although the Pella, Iowa UV system is operational, it is still under the manufacturer's warranty and the manufacturer has been performing the required maintenance for this facility; therefore, actual O&M costs were not available.

5.5 TYPICAL O&M PROBLEMS

Typical O&M problems encountered, and associated suggestions for improved operation determined during conversations with plant personnel are listed in Tables 5-9 and 5-10, respectively. Most of the problems identified were maintenance-related items. A more detailed discussion of the O&M problems encountered with the ozone systems surveyed is presented in Section 6.

Typical O&M problems encountered with the UV systems included:

- Ballasts on UV lamps overheat and shut down the system.
- Unit does not consistently disinfect plant effluent to degree required by NPDES permit.
- Foam build-up interferes with operation of cleaning mechanism.
- Low flow rate causes unit to overheat.
- Algae accumulations in unit interfere with system operation.

Table 5-5

Ozone Plants -
Typical O&M Problems as Reported by Plant Operators

-
- Multiple and frequent ozone generator cell failures.
 - Silicone control rectifier (SCR) failures.
 - Severe foam problems with contact tank gas recovery system.
 - Ozone system electronics are too complicated for WWTP personnel to perform routine maintenance and repair work.
 - Corrosion problems with O₃ analyzer valve components.
 - Ozone contact tanks were constructed below the system control room and O₃ leaks cause instrumentation rubber seals to corrode.
 - System equipment (i.e., generators, compressors) is very noisy.
 - The system includes numerous pieces of equipment that must be maintained.
 - System instrumentation must be continually calibrated.
 - Ozone generators are a high maintenance item; continually blow fuses.
 - Corrosion problems with compressors due to wet gases.
 - Catalyst poisoning in O₃ destruction system.
 - No dew point monitoring equipment provided with ozone system.
 - Excessive heat build-up in O₃ generator room causes generator heaters to shut down units.
 - Non-compatible materials of construction; rubber sleeves on compressors; chlorinated rubber-based paint used to seal ozone contact chamber.
 - Dew point meters not reliable.
 - Improper (i.e., too high) dew point setting causes dielectric failures.
 - Improper cleaning procedures for dielectric tubes causes pitting and cracking of tubes.
-

Table 5-10

Ozone Plants - Operator Suggestions

- Ensure an adequate air filtration system is installed.
- An experienced and qualified instrumentation person should be part of the WWTP's operating staff.
- Ozone contact tanks should be sited away from other buildings and equipment to avoid corrosion and safety problems.
- An O_3 destruction unit may not be required if contact tank off-gases can be vented in an isolated area away from WWTP buildings.
- System should include a carrier gas O_3 monitor to aid in determining when unit needs to be cleaned.
- Provide a dry gas purge system for compressors.
- Provide a foam suppression system in the ozone contact tank and for gas destruction system.
- Provide ample air circulation in ozone generator room to prevent excessive heat build-up.
- Equipment should be housed inside a building for protection and prevention of corrosion and freezing problems.
- The ozone generator room must be kept very clean, otherwise the generator cells will short-out and blow fuses.

SECTION 6

SETTING PRIORITIES FOR O&M PROBLEMS

6.1 OZONE PLANTS

The frequency of occurrence of the various problems associated with ozone disinfection systems that were identified during the study is indicated in Table 6-1. It can be seen that the most prevalent problems included:

- Inefficient ozone destruction in the destruct unit.
- Ozone generator cell failure.
- Ozone leakage from generator.
- Inefficient performance of inlet air desiccant dryer.
- Ozone contact tank improperly sealed.
- Malfunctions in ozone concentration monitors.

Detailed descriptions and discussions concerning the problems listed in Table 6-1 are presented in the individual plant trip reports included in the appendix. Remedial measures to correct these problems are summarized in Section 7.

6.2 UV PLANTS

Problems experienced at the UV plants visited during the project are listed in Table 6-2. It can be seen that no prevalent problem reoccurred at each plant. Detailed descriptions and discussions of the problems are presented in the individual plant trip reports included in the appendix.

Table 6-1

O&M Problems Identified at Ozone Plants

Problem	Plant No.												Total Number Occur- rences
	1	2	3	4	5	6	7	8	9	10	11	12	
Foam build-up in O ₃ contact tank and resultant fouling of destruct unit catalyst	X					X							2
Ozone generator cell failure	X			X					X		X		4
Poor ozone transfer efficiency in the O ₃ contact tank	X	X										X	3
O ₃ leakage from generator	X			X	X								3
Poor O ₃ destruction in the destruct unit	X	X	X			X							4
Shut down of feed-gas compressors due to faulty surge/vibration monitors	X												1
Failure of silicone control AC rectifiers (SCR)	X			X									2
System air compressors discharge more air than required			X										1
Refrigerant dryer overloaded			X										1

Table 6-1
(continued)

O&M Problems Identified at Ozone Plants

Problem	Plant No.												Total Number Occur- rences
	1	2	3	4	5	6	7	8	9	10	11	12	
Inefficient performance of inlet air desiccant dryer		X	X						X		X		4
Stand-by electrical generator will only operate one O ₃ generator		X											1
Ozone piping leakage		X											1
Ozone contact tank not covered and/or sealed properly resulting in O ₃ leakage		X	X		X						X	X	5
High O ₃ levels in WWTP non-potable water system		X											1
Insufficient number of ozone monitors at WWTP		X											1
Dielectric tubes overheating and breaking due to corrosion problems and dirt accumulation				X					X		X		3

Table 6-1
(continued)

O&M Problems Identified at Ozone Plants

Problem	Plant No.												Total Number Occur- rences
	1	2	3	4	5	6	7	8	9	10	11	12	
Malfunction of cooling water flow and O ₃ generator gas pressure sensors/alarms			X										1
Fluctuating ozone generation			X										1
Voltage surges that damage electrical components and instrumentation			X								X		1
Malfunction of O ₃ concentration monitor			X	X	X						X		4
High noise level around ozone generation equipment			X							X			2
Drive belts on exhaust fans in O ₃ generation room frequently fail				X									1
O ₃ generator side panel fasteners frequently fail				X									1
O ₃ gas sampling equipment leaks				X	X								2

Table 6-1
(continued)

O&M Problems Identified at Ozone Plants

Problem	Plant No.												Total Number Occur- rences
	1	2	3	4	5	6	7	8	9	10	11	12	
O ₃ generator shut- down due to high temperatures in gen- erator room							X						1
O ₃ exhaust vent located too near building air intake causing high ambient O ₃ concentration inside building								X					1
Ice build-up at out- let of O ₃ exhaust vent caused blockage of vent								X					1
Switch-over valves on inlet air drying towers malfunction								X					1
Dielectric fuses al- low current flow even when burned-out								X					1
Residual ozone meter readings in O ₃ contact tank are un- stable								X			X		2
Recompression blowers at O ₃ contact tank malfunction										X	X		2

Table 6-2

O&M Problems Identified at UV Plants

Problem	Plant No.		
	13	14	15
Sudden flow surge into UV chamber causes damage to UV lamps and quartz sleeves	X		
Faulty powerstat does not allow operation of UV system at low power levels resulting in electrical energy wastage	X		
Light Emitting Diode (LED) does not give true indication if UV lamp is actually operational	X		
UV lamp wiper mechanism frequently jams	X		
Malfunction in water level monitoring system in UV chamber		X	
Faulty UV chamber influent flow meter		X	X
Foam build-up in UV chamber		X	
Biological growth on teflon tubes occurred during intermittent flow conditions			X

SECTION 7

RECOMMENDATIONS FOR IMPROVED PERFORMANCE

Remedial actions taken to correct the problems listed in Section 6 concerning ozone and UV disinfection are presented in Tables 7-1 and 7-2, respectively. The problems encountered and the associated solutions implemented should be considered during design of ozone and UV disinfection systems.

Table 7-1

Remedial Actions Taken to Correct O&M Problems
Observed at Ozone Plants

Problem	Remedial Action
Foam build-up in O ₃ contact tank	Provide foam sprayer in contact tank or separate foam spray tanks between O ₃ contact tanks and O ₃ destruct unit
O ₃ generator cell failure	Purge O ₃ generator prior to start-up to ensure the unit is clean and free of dust or rust particles
Poor O ₃ transfer efficiency in the O ₃ contact tank	Routinely inspect O ₃ diffusers and clean when required
O ₃ leakage from generator	Replace damaged cells in generator; adequately ventilate the O ₃ generator room
Poor O ₃ destructor performance	Increase the quantity of catalyst in the destruct unit; install an electric air pre-heater prior to the destruct unit; check for leakage from destruct unit; replace catalyst
Premature shut-down of feed-gas compressor	Replace faulty surge/vibration monitor
Failure of SCR	Determine cause of problem and replace faulty SCR
System air compressors discharge more air than required	Change pulley size to reduce operating speed
Refrigerant dryer overloaded	Check the inlet air compressor water seal system to ensure the compressor is not overheating and heating the inlet air to the dryer

Table 7-1
(continued)

Remedial Actions Taken to Correct O&M Problems
Observed at Ozone Plants

Problem	Remedial Action
Inefficient performance of inlet air desiccant dryer	Re-charge the dryer with new desiccant material; check that the desiccant regeneration heaters are not operating at too high a temperature; install a dew point indicator/controller to initiate the desiccant regeneration cycle automatically when "wet air" is being discharged from dryer; check the desiccant to ensure it is not being contaminated with sulfate, chloride, iron (rust) or some other constituent; clean the purge-air filter
Stand-by electrical generator will only operate one O ₃ generator at a time	Size stand-by electrical generator to operate sufficient number of O ₃ generators
O ₃ piping leakage	Install O ₃ resistant piping (stainless steel); use welded joints, <u>not</u> threaded joints
Ozone contact tank not covered and/or properly sealed	Completely cover and tightly seal the O ₃ contact tank; do not use the O ₃ contact tank for a filter backwash supply tank; install additional seal/gasket material
High O ₃ levels in the WWTP non-potable water system	Do not use ozonated water as a non-potable water supply source
Insufficient number of O ₃ monitors at WWTP	Provide O ₃ monitors for both the lab and other plant working areas; provide stand-by O ₃ monitor

Table 7-1
(continued)

Remedial Actions Taken to Correct O&M Problems
Observed at Ozone Plants

Problem	Remedial Action
Dielectric tubes over-heating and breaking due to corrosion problems	Check for leaky air release parts in O ₃ generator cooling water system; add corrosion prevention chemicals to the cooling water; thoroughly clean dielectrics and final rinse with alcohol
Malfunction of cooling H ₂ O flow and O ₃ generator gas pressure sensors/alarms	Check for rust particle fouling; add rust prevention chemical to cooling H ₂ O; check for ozone destruction of diaphragms in pressure sensors
Fluctuating ozone generation	Check operation of O ₃ meters; increase frequency meters are cleaned and calibrated; check generator operation and power source
Voltage surges that damage electrical components and instrumentation	Check for flow surges to plant due to on-off operation of pumping stations which cause O ₃ dosage control to fluctuate; dampen flows to WWTP; install voltage-control transformer
Malfunction of O ₃ concentration monitor	Increase frequency of cleaning and calibration check to once per day if required
High noise levels around O ₃ generation equipment	Provide noise abatement provisions around compressors and generators; install acoustical material around equipment and in equipment rooms
Drive belts on exhaust fans in O ₃ generation room frequently fail	Install fans so drive belts have minimum exposure to exhausted air; use more ozone resistant belts
O ₃ generator side panel fasteners frequently fail	Install heavy-duty screw-type fasteners on side panels

Table 7-1
(continued)

Remedial Actions Taken to Correct O&M Problems
Observed at Ozone Plants

Problem	Remedial Action
O ₃ gas sampling equipment leaks	Ensure pumps, valves, connections, and piping are constructed of O ₃ resistant material
O ₃ generator shut-down due to high temperatures in generator room	Provide ventilation in O ₃ generator room
O ₃ exhaust vent located too near building air intake causing high ambient O ₃ concentration inside building	Relocate exhaust vent; extend height of exhaust vent
Ice build-up at outlet of O ₃ exhaust vent caused blockage of vent	Heat trace and insulate the exhaust vent
Switch-over valves on inlet air drying towers malfunction	Pneumatic cylinders must be rebuilt
Dielectric fuses allow current flow even when burned-out	Replace fuses with different type
Residual ozone meter readings in O ₃ contact tank are unstable	Relocate probe closer to section of contact tank where O ₃ is being injected
Recompression blowers at O ₃ contact tank malfunction	Check seals and bearings for deterioration due to O ₃ attack

Table 7-2

Remedial Actions Taken to Correct O&M Problems
Observed at UV Plants

Problem	Remedial Action
Sudden flow surge into UV chamber causes damage to UV lamps	Slowly open inlet valve into UV chamber; position mechanical wiper mechanism in the middle of the chamber for added support
Faulty powerstat does not allow operation of UV system at low power levels resulting in electrical energy wastage	Replace powerstat with unit that allows finer adjustment; check minimum power requirements for UV lamps; replace powerstat with shut-off switch that shuts off lamps for close control
Light Emitting Diode (LED) does not give true indication if UV lamp is actually operational	Check for faulty LED, burned out LED, or malfunctioning ballast
UV lamp wiper mechanism frequently jams	Prior to start-up of unit, ensure that the wiper has not dried out and become stuck to UV lamps; routinely check wiper for proper alignment
Malfunction in water level monitoring system in UV chamber	Provide adequate difference in elevation between high and low level settings; use time-delayed relays for water level sensors
Faulty UV chamber influent flow meter	Routinely check flow meter calibration; ensure it accurately monitors entire flow range

Table 7-2
(continued)

Remedial Actions Taken to Correct O&M Problems
Observed at UV Plants

Problem	Remedial Action
Foam build-up in UV chamber	Provide foam control measures, such as water sprays, prior to UV chamber; thoroughly clean tubes prior to start-up to prevent scum build-up and jamming of lamp wiper
Biological growth on teflon tubes occurred during intermittent flow conditions	Slightly slope the teflon tubes to ensure they remain full of water during no-flow periods

APPENDIX
PLANT TRIP REPORTS

Index

Plant No.	Plant*	Location	Disinfection System	
			Ozone	UV
1	Rocky River Regional WWTP	Concord, NC	X	
2	Upper Thompson Sanitation District	Estes Park, CO	X	
3	Frankfort WWTP	Frankfort, KY	X	
4	Southwest WWTP	Springfield, MO	X	
5	Brookings WWTP	Brookings, SD	X	
6	Murfreesboro WWTP	Murfreesboro, TN	X	
7	Madisonville WWTP	Madisonville, KY	X	
8	Monroe WTP	Monroe, MI	X	
9	Bay Metro WTP	Bay City, MI	X	
10	Charles J. Des Baillets WTP	City of La Salle, CAN	X	
11	Pierrefonds WTP	Pierrefonds, CAN	X	
12	Sherbrooke WTP	Sherbrooke, CAN	X	
13	Sents Creek WWTP	Pella, IA		X
14	Sanford WWTP	Sanford, ME		X
15	Hatfield WWTP	Hatfield, AR		X

*WWTP - Wastewater Treatment Plant.
WTP - Water Treatment Plant.

ROCKY RIVER REGIONAL WASTEWATER TREATMENT PLANT CONCORD, NORTH CAROLINA

GENERAL

Concord is located approximately 15 miles northeast of Charlotte, North Carolina (see Figure 1). The treatment facility presently has a daily average flow of 12.2 mgd (24 mgd design). The plant was constructed between 1976 and 1980 at a cost of \$32 million. The wastewater treatment processes at Concord include:

- Bar screening.
- Primary clarification.
- First stage oxygen-activated sludge.
- Secondary clarification.
- Second stage nitrification.
- Final clarification.
- Ozone disinfection of the final effluent.

The plant flow diagram is shown in Figure 2. A site visit was conducted on 30 March 1982.

The primary purpose for ozonation at the Rocky River Regional Wastewater Treatment Plant is disinfection. The ozone disinfection system was designed and constructed by Union Carbide. The plant currently treats approximately 5 mgd of textile industry wastewater. The plant discharges into Rocky River, which is classified as "C" water quality limited. Discharge limits are 20 mg/L BOD₅ (in summer months), 30 mg/L suspended solids, 13 mg/L ammonia nitrogen, and 5 mg/L dissolved oxygen (in summer months).

OZONE SYSTEM DESCRIPTION

The ozone system is designed for a 33.6 mgd flow and an ozone dose of 17 mg/L at 90 percent ozone transfer efficiency. A two-train, two-stage contactor is utilized, with each stage having an internal dimension of 25 ft by 25 ft by 17 ft (SWD), with 2 ft of freeboard. The ozone system's generation capacity is 4,360 ppd at a concentration of 3 percent by weight using 16 of the 17 Union Carbide LG-90 ozone generators (each rated at 270 ppd). Design parameters for the ozone system are presented in Table 1.

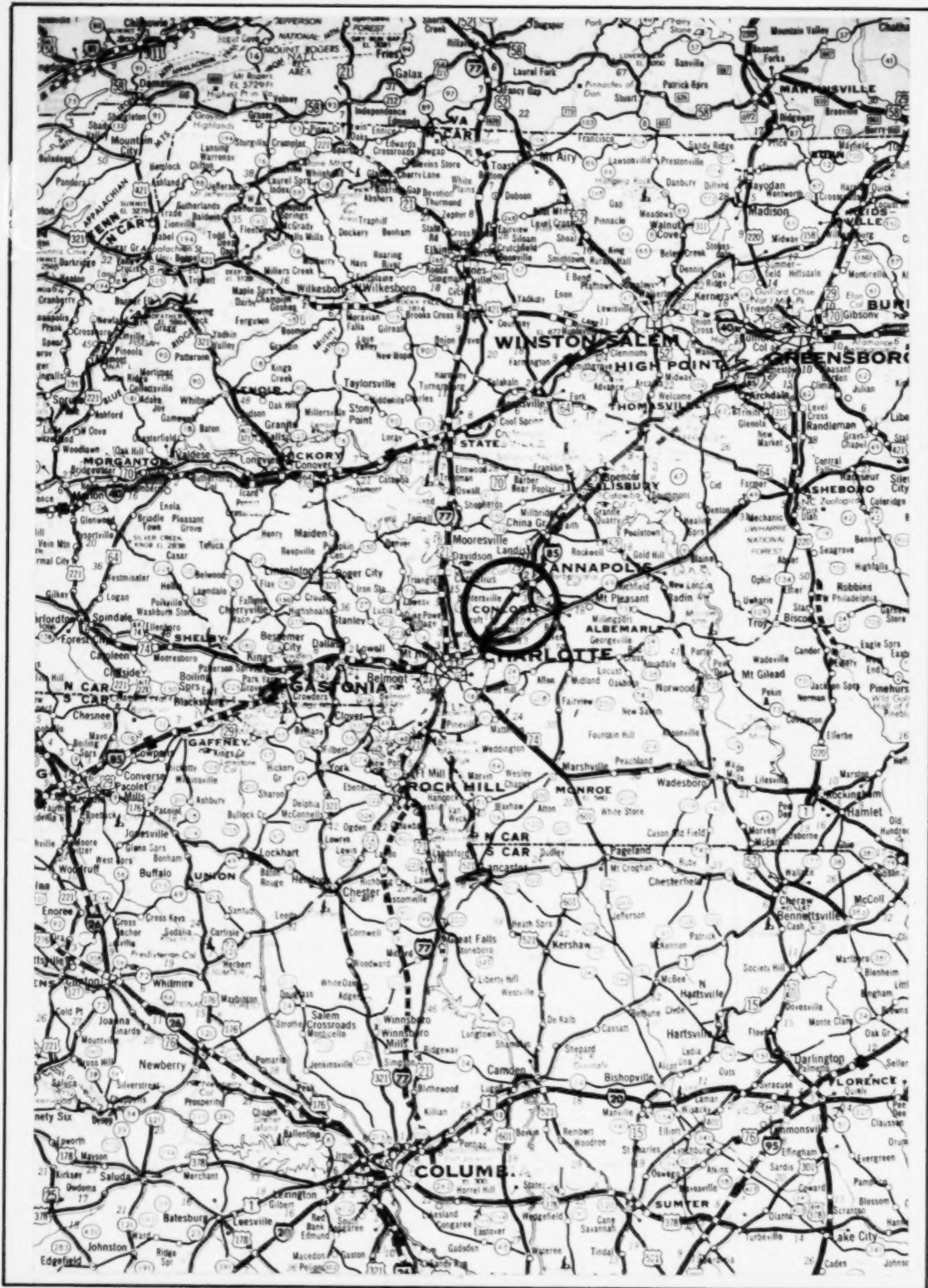


FIGURE 1 PLANT LOCATION MAP

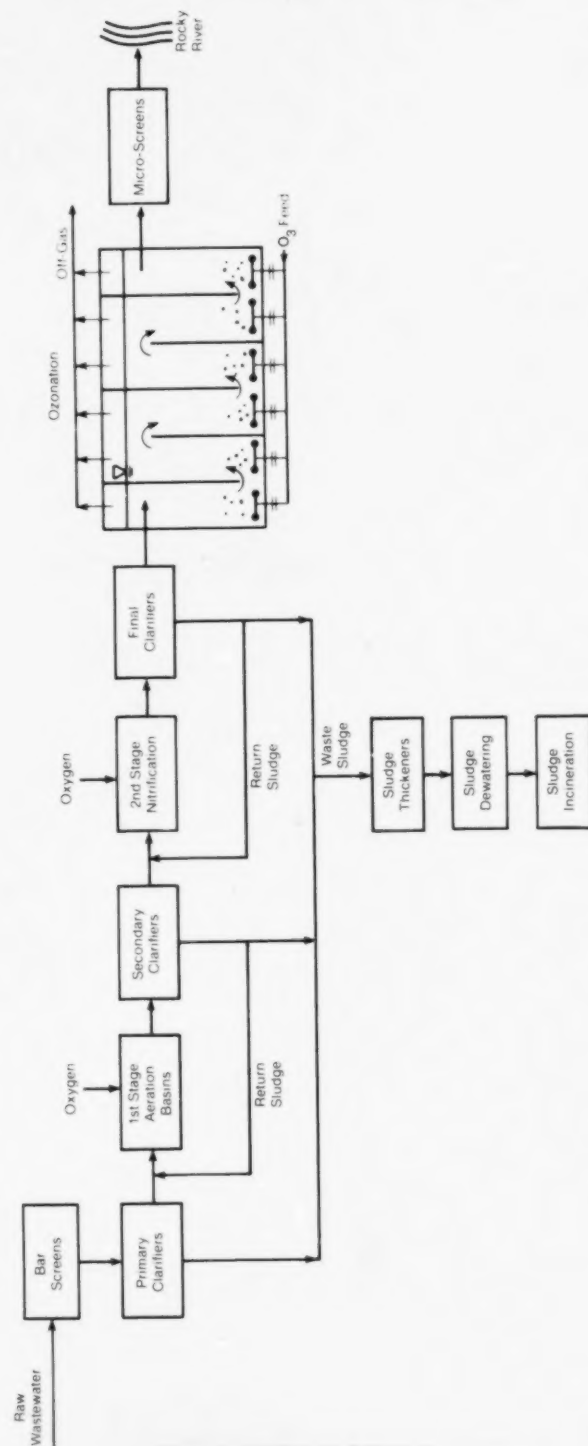


FIGURE 2 PLANT FLOW DIAGRAM

In Table 1, two parallel trains are used with each train having two "stages" (see Figure 3). The "stages," unlike those in the pure oxygen reactors, are designed to promote plug flow rather than act as complete mixed stages. Providing stages allows adjustment to the ozone dose in the front and rear halves of the train.

Table 1

Ozone System Design Parameters
Concord, North Carolina

Parameter	Average	Design
Q, mgd	24	33.6
O ₃ Contact time, minutes	19	13.6
O ₃ dose, mg/L	14	14
O ₃ utilization, percent	90	90
O ₃ generated, lb/day	3,114	4,360
O ₂ feed to generators, tons/day	51.2	70.3
O ₃ generated weight percent	3.0	3.0
Effluent DO ₃ , mg/L	0	0
Effluent DO, mg/L	30	30
<u>Gas Flow Per Train, cfh</u>		
Stage 1 Feed:	13,000	17,900
Stage 2 Feed:	13,000	17,900
Train Vent:	26,700	37,750

Ozone dissolution is accomplished using ceramic disc diffusers located on the contactor floor. The diffusers are designed to provide a 90 percent ozone transfer efficiency at design gas flows, assuming an initial zero dissolved ozone level.

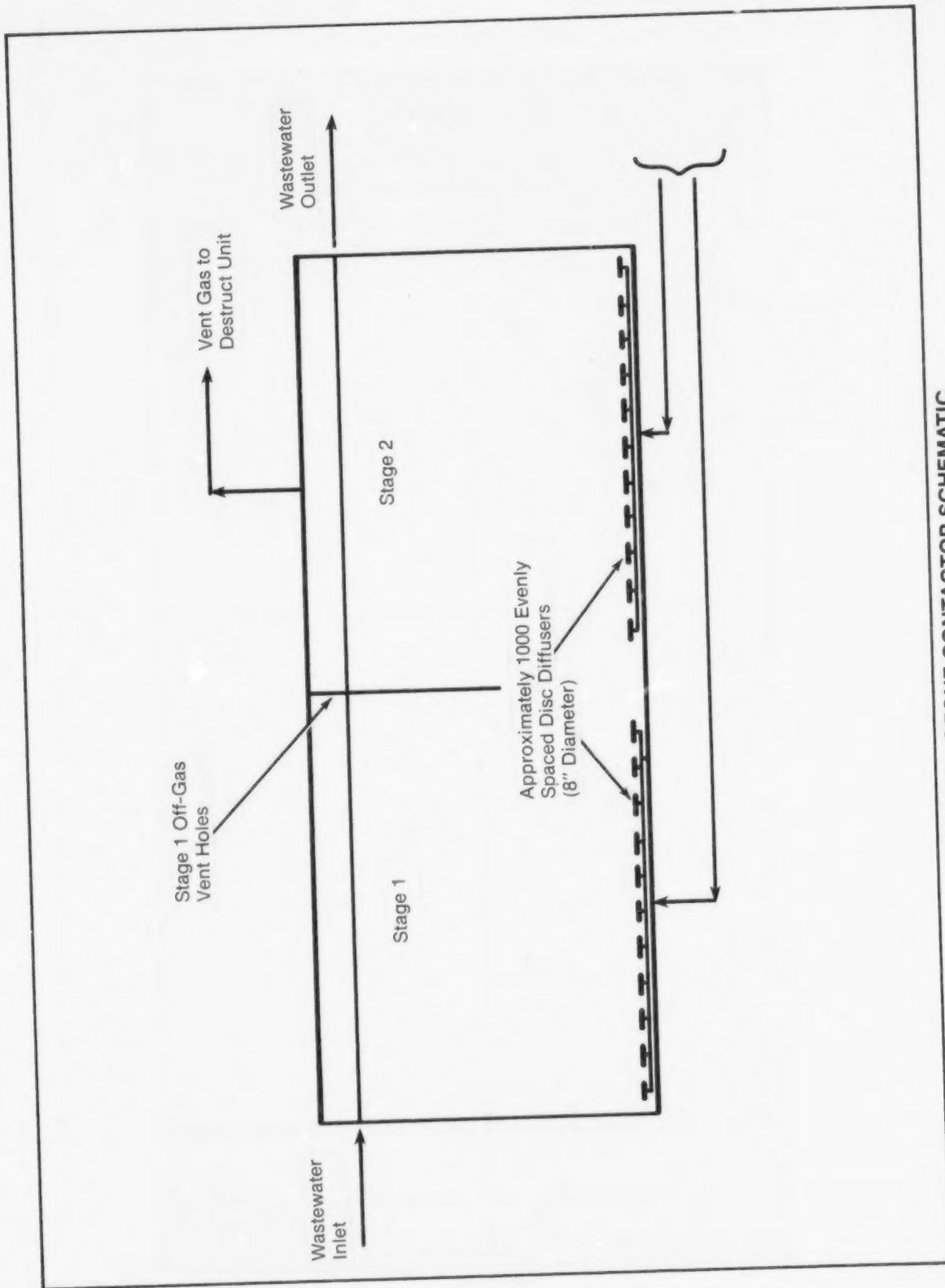


FIGURE 3 OZONE CONTACTOR SCHEMATIC

Oxygen from the Cryo plant is fed to the ozone generators by a 100-horsepower centrifugal compressor. The system includes two feed compressors, with one serving as a spare. Two heat exchangers (one spare) are provided to raise the ozone contactor vent gas stream to a minimum temperature of 104°F, using heat from the ozone feed compressor discharge. Thus, the heat exchanger simultaneously cools the ozone generator feed gas.

The feed compressors will supply 70,900 scfh, 56,720 scfh, and 52,670 scfh at three specified ozone production levels of 4,360, 3,500, and 2,620 lb/day, respectively. At the two higher production rates, ozone is generated at 3 percent by weight; however, at the 2,620 lb/day rate the generated ozone concentration is 2.4 percent by weight.

Sixteen of the LG-90 ozone generators installed (one serving as a spare) are needed to provide the design ozone production rate of 4,360 lb/day. Lower production rates are met by adjusting individual generator production rates and/or taking generators off-line, depending on the ozone production requirements.

Contacting off-gas first passes through two foam elimination tanks arranged in series as shown in Figure 4. The vent gas then passes through a stainless steel mesh that "demists" the vent gas. A modular catalytic ozone decomposition system is used. The gas discharged into the catalytic ozone-destruct unit is preheated to approximately 104°F. The ozone-destruct unit consists of a particle filter and two catalyst filters in series. The unit was supplied by the Mine Safety Appliance Company, and it employs their trade name "Hopcalite." A 50-horsepower centrifugal vent "booster" compressor (one spare was also supplied) delivers the contactor vent gas to the first and second stages of the pure oxygen-activated sludge system.

FACILITY OPERATIONS

Ozone System Control

The pure oxygen-activated sludge and ozone disinfection systems are integrated designs; therefore, the operating mode of one affects the operation of the other. The plant wastewater flow rate is monitored and electromechanically converted into a 4-20 ma signal, which operates a controller that feeds oxygen to the ozone generators proportional to the wastewater flow. A similar signal proportionally adjusts the power to the ozone generators and, theoretically, the system maintains a given weight percent of ozone generated for each applied ozone dose.

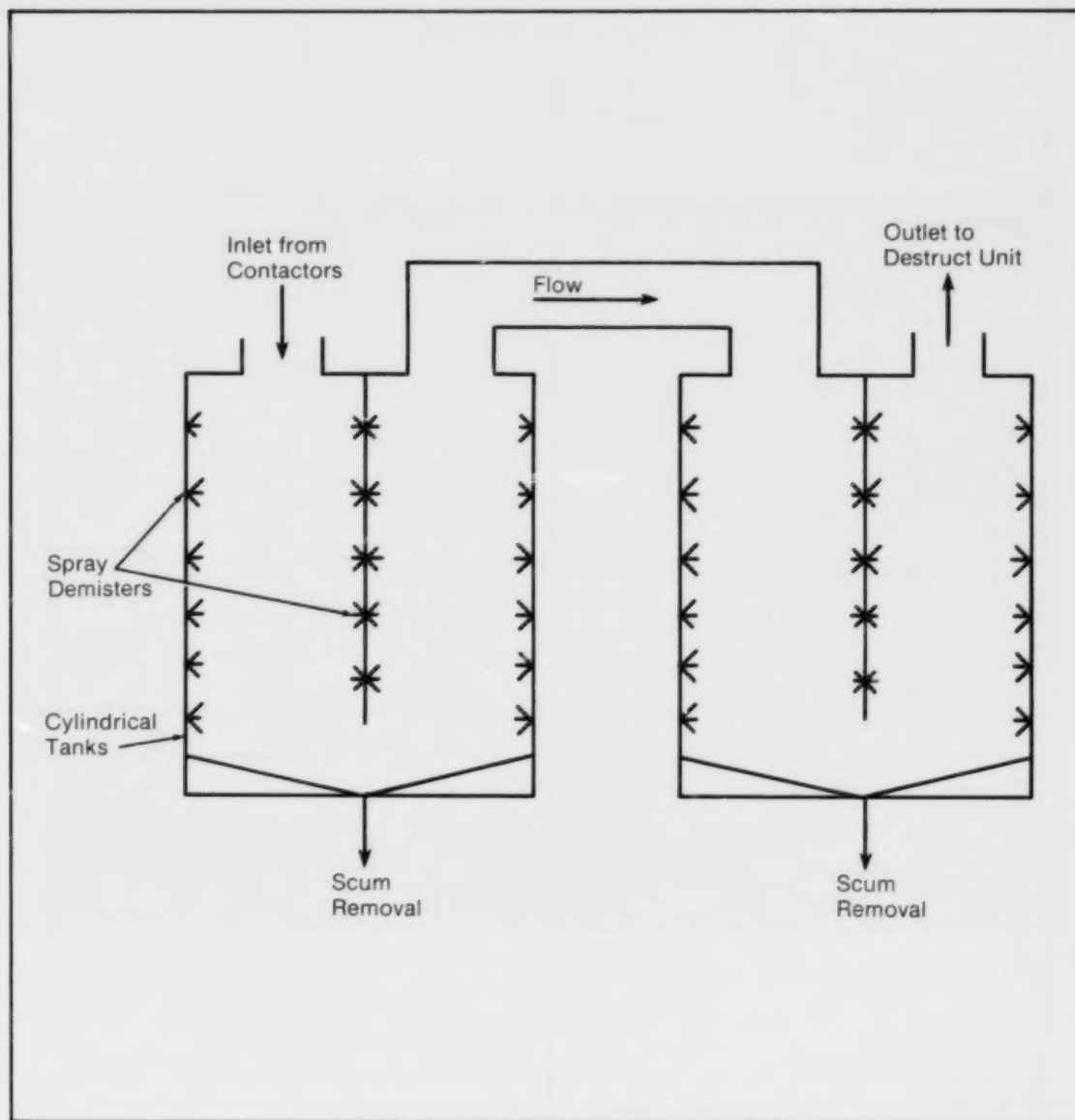


FIGURE 4 FOAM ELIMINATION SYSTEM

Set operating pressures are maintained in the first stage pure oxygen reactors. A pressure-indicator-controller (PIC) opens the oxygen feed valves to the reactors if the pressure falls below the set point and closes down the valves above another set point. If the ozone system is providing less oxygen than is required by the pure oxygen system, the drop in pressure in the feed oxygen line signals for additional oxygen through a bypass line (bypasses the ozone system). Should the ozone system provide oxygen in excess of that required by the pure oxygen system, the increase in pressure in the oxygen feed line signals the vent valve of the first stage oxygen-activated sludge reactor to open, creating a false demand and allowing the excess gas to go through the second stage reactors.

If it is found that the ozone dose requirements are lower than specified, the dose set point can be lowered somewhat by reducing the gas flow/wastewater flow set point. For a large dosage drop a more economical procedure is to lower the ozone-generated weight percent and realize ozone generation savings with increased generation efficiencies.

Start-Up and Operational Problems

The Rocky River Regional Wastewater Treatment Plant has experienced relatively few operational problems and has been down for only 10 days since its original start-up in October of 1980. The major start-up problem with the ozone disinfection system was the generation of large quantities of foam in the contact chamber. This foam traveled through the exhaust piping and into the destruct unit, thereby wetting the catalyst material and reducing its efficiency for destroying ozone to virtually zero. The foaming problem was solved by installing two foam elimination tanks in series upstream of the destruct units. A schematic representation of these defoaming chambers is shown in Figure 4.

Numerous ozone generator cell failures occurred during the first year of operation. Cell failure is distinguished by the discoloration and cracking of the porcelain faces of the generating (Lowther) plates. Between October 1980 and August 1981, 202 fuses of the 765 in the total system failed. Each blown fuse represents two generating cells going out of service. As a point of reference, each generator has three banks of 30 cells each for a total of 90 cells per generator. In addition, the replacement of one of these 30 cell banks costs approximately \$4,500 and requires a 6-month delivery time. The generation cells are supplied by Denalco. The actual reason for cell failure is not clearly understood. The equipment vendor believes that the cell failure is due to insufficient purging of the generators prior

to start-up, thereby causing small particles of rust to enter the generation cells. Since the beginning of April 1982, cell failure has dramatically decreased, and the current failure rate is approximately five cells per month. The only solution known by the plant superintendent for cell failure is to replace the appropriate 30-cell bank once the generation rate has dropped below acceptable levels.

The longer-term operational problem of poor ozone transfer efficiency has become apparent since September of 1981. Prior to that time typical transfer efficiencies averaged 87 percent, but subsequently have dropped to approximately 50 percent. The poor transfer efficiency has periodically caused the plant to be out of compliance with their fecal coliform limitation. Fecal coliforms have ranged between 100 and 100,000 counts/100 ml. It is suspected that the poor transfer efficiency being achieved is caused by the large industrial wastewater contribution from a nearby textile industry. This contribution represents 40 percent of the plant's flow and is believed to contain large quantities of relatively unbiodegradable surfactants, which can reduce transfer efficiency. At the present time, the plant has not found the solution to this poor transfer efficiency; however, they have retained a consulting engineering company to study the problem and make appropriate recommendations.

Additional operational problems include the leakage of ozone from the ozone generators in the generating building. At times ambient ozone concentrations exceed 0.1 ppm and range up to 0.4 ppm. It is suspected that damaged cells are leaking. The current solution is to have the operators turn on the exhaust fans in the generator room prior to entering. The plant's consulting engineers are studying this problem and are expected to make recommendations in the near future.

The poor ozone transfer efficiencies being achieved in the contacting units have resulted in the destruct units being unable to adequately destroy the ozone in the contactor off-gas. This problem is more acute during cold weather periods due to even poorer ozone transfer efficiencies in the contact chambers. The approach implemented to correct this problem is to increase the quantity of catalyst in the destruct units by an additional 50 percent. Also, there is no direct electrical heating unit prior to the ozone destruct unit; only the gas-to-gas heat exchangers exist. The problem seems to be under control since the inventory of catalyst in the destruct units was increased.

During start-up, the feed gas compressors frequently shut down because the surge/vibration controllers would activate without apparent cause. This problem was remedied by replacing and reworking the monitors.

Problems with the silicon control AC rectifiers (SCR) have continually hampered operation of the ozone disinfection system. When an SCR fails, a cascading effect occurs which blows the main circuit breaker for the ozone generation facilities. Each ozone generator has three SCR's and each costs approximately \$170. No solution has been found except to replace the SCR's upon failure.

Operations and Maintenance Staff

The Rocky River Regional Wastewater Treatment Plant staff includes 18 operators, 4 laboratory personnel, an engineer, and a supervisor. Plant personnel seem to be adequately trained to operate the ozone-generating equipment. Operator attitude towards instrumentation is generally very good, with the exception of their use of the UV ozone monitors. Plant personnel stated that the UV ozone monitors are quite unreliable and require electronic calibration once a month.

The plant's laboratory seems well equipped for monitoring and controlling the ozone disinfection system. The laboratory is able to conduct the idometric wet test method for determining gaseous ozone concentrations. The plant chemist has even set up a small bench-scale ozone reactor in order to predict required ozone concentrations for effective fecal coliform removal. The laboratory personnel's attitude and interest towards the ozone disinfection system was excellent.

MAINTENANCE

As previously mentioned, the ozone disinfection system has only been off-line for approximately 10 days since its start-up in October of 1980. Those 10 days were for scheduled maintenance of the ozone generation system. As outlined in the O&M Manual, the following preventive maintenance tasks should be performed on a regular basis for each ozone generator:

- Once per shift record all generator operating conditions, including voltage, amperage, gas line pressure, flow rate, and cell temperature.

- Each day determine the ozone production rate of the generator and the concentration of ozone in the gas generated.
- Every six months shut down the generator for a complete service inspection and perform the following tasks:
 - Check all wiring connections for tightness.
 - Check all gas connections for tightness.
 - Check all cell fuses and module ground connections.
 - Check for generator leaks if ozone is detected in the atmosphere.
 - Check all modules for grease and grime build-up.

The plant's current spare parts inventory for the ozone generation equipment is given in Table 2.

Table 2

Ozone Generation Spare Parts Inventory
Rocky River Regional WWTP

Part	Inventory Quantity
Master Oscillator	1
Relays Potter Brumfield KRPl1AG	2
Remote Driver Al382131	6
Transformer Isolation 115V-115V 35 VA Triad	2
Potentiometer Model 860 Res. 5 Kr 8032	1
Relay Potter Brumfield KHPl7AlB	1
Signal Limiter Model SC-1362	1
Ratio & Bias Trans. Model SC-1398	1

OPERATION AND MAINTENANCE COSTS

A breakdown of operation, maintenance, and ozone production costs is given in Table 3. Ozone generation costs are based on

Table 3

Ozone Cost Sheet
Rocky River Regional Wastewater Treatment Plant

O₃ Generation Rate = 1,010 kg/d at 14 mg/L
FCI = \$825,000 (equipment, piping, electrical, instrumentation)

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power	9.69	3.7	36
Operating Labor (.325 MY) (including repair and labor supervision)			3
Repair Materials			1
Supplies (10% O.L.)*			<u>1</u>
Total Operating Cost			41
<u>Overhead Cost</u>			
Insurance			1
Amortization (7% at 20 years)			<u>21</u>
Total Overhead Cost			22
TOTAL OZONE COST ¢/kg (¢/lb)			63 (28)

MY, Man Year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

9,800 kilowatt hr per day and 2,230 lb of ozone generated per day as calculated for the month of January in 1982. The electrical power requirements for the ozone generating units are 6,850 kilowatt hours per day and 2,950 kilowatt hours per day for the ozone contacting system for January 1982.

UPPER THOMPSON SANITATION DISTRICT
ESTES PARK, COLORADO

GENERAL

The Upper Thompson Sanitation District (UTSD) is located approximately 60 miles northwest of Denver in Estes Park, Colorado (see Figure 5). The UTSD uses ozone for disinfection of its wastewater. The system was designed in 1972 and placed in operation in 1976. It was the first disinfection process of its type in the United States, and was known to be an innovative design. The UTSD Board of Directors selected ozone not only to achieve disinfection, but also to attain the added benefits of color removal, turbidity removal, a non-toxic effluent, suspended solids reduction, and general aesthetic superiority. Superior quality wastewater has been discharged during those periods when the ozone system has operated satisfactorily. However, continuous operation has not occurred because of periodic high ozone levels in the staff working environment. Also, equipment malfunctions, in particular poor performance of the desiccant dryers, has caused frequent system shutdowns. The system has not been in use since 1980.

A flow schematic for the UTSD facility is shown in Figure 6. All wastewater is pumped to the plant from lift stations serving two river basins and discharged to a flow equalization basin. Equalized flow is directed to a grit chamber, then to an activated sludge process. Secondary clarifier effluent is pumped to a nitrification tower and then routed to mixed media pressure filters. Filter effluent is disinfected in the ozone contact basin and subsequently discharged to a filter backwash water storage tank. The overflow from the storage tank discharges to the Big Thompson River. Waste sludge and scum generated in the plant is pumped to an aerobic digester for stabilization. Digested sludge is dewatered via a pressure belt filter and is subsequently hauled to a sanitary landfill.

The plant's NPDES permit requirements are presented in Table 4.

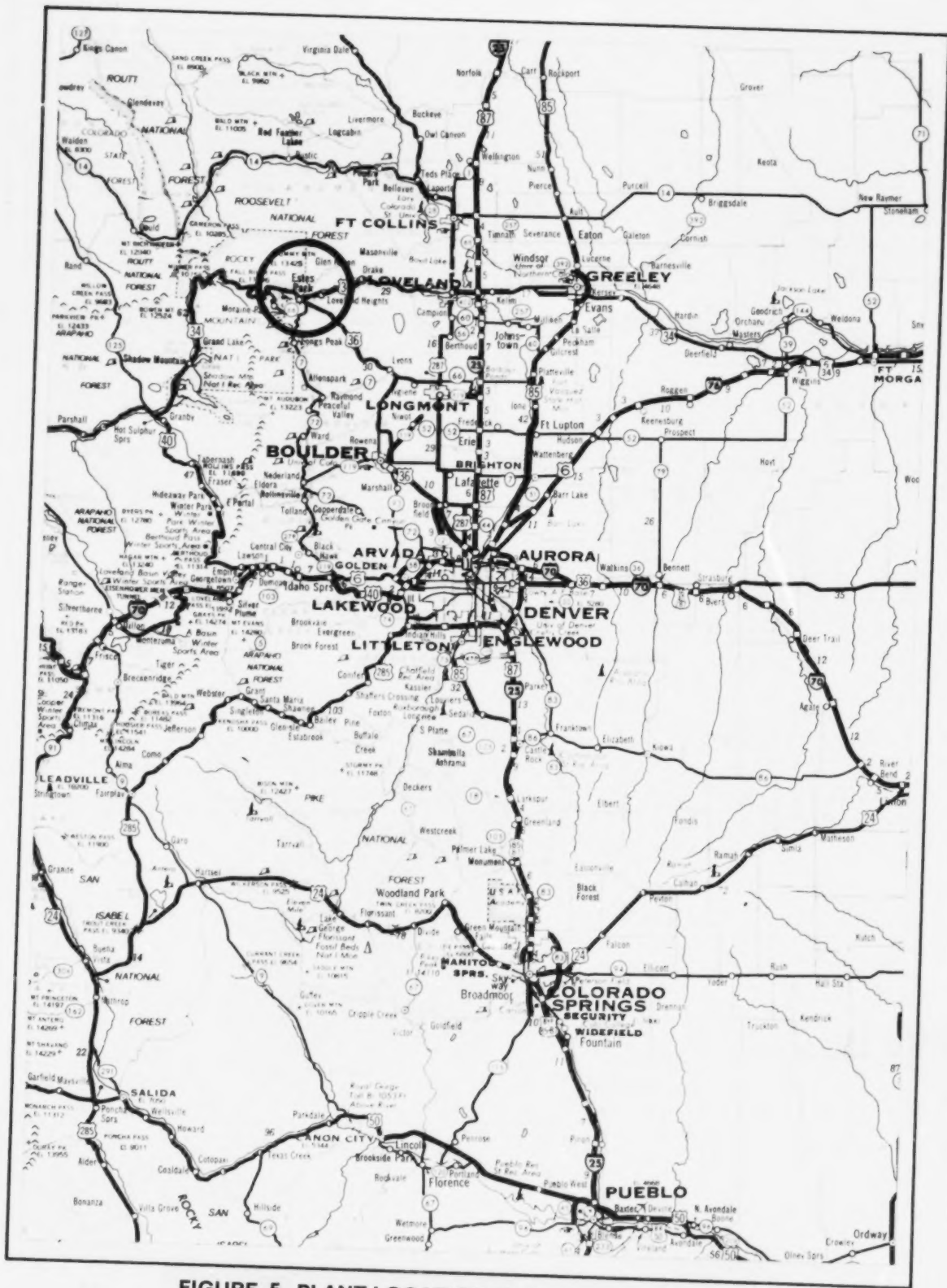


FIGURE 5 PLANT LOCATION MAP

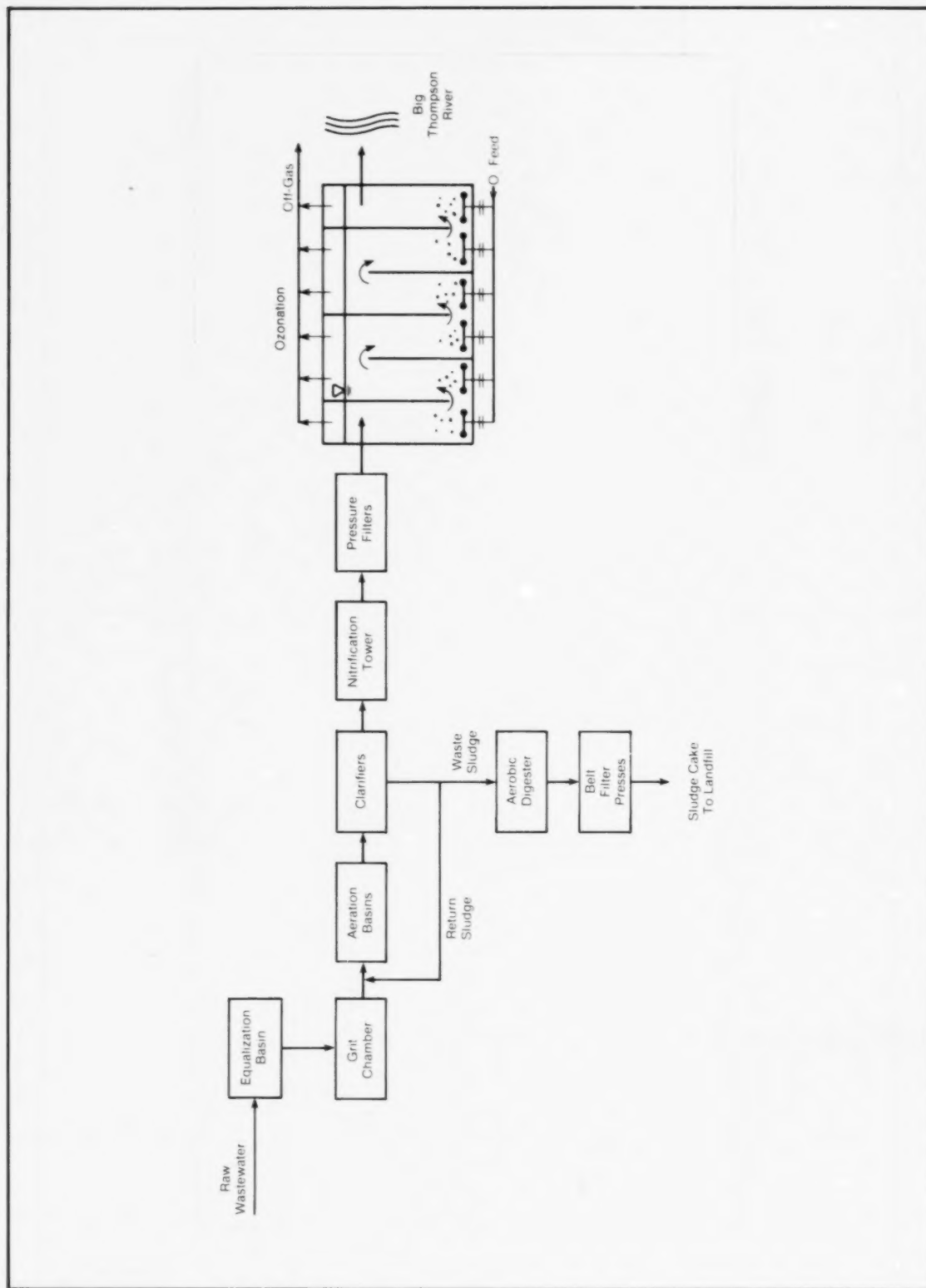


FIGURE 6 PLANT FLOW DIAGRAM

Table 4

Estes Park, Colorado
Upper Thompson Sanitation District
NPDES Discharge Limitations

Parameter	Concentration Limit
BOD ₅ , monthly maximum	45 mg/L
BOD ₅ , monthly average	30 mg/L
TSS, monthly maximum	45 mg/L
TSS, monthly average	30 mg/L
Chlorine Residual	0.1 mg/L
Fecal Coliform, summer monthly average	200 counts/100 ml
Fecal Coliform, winter monthly average	400 counts/100 ml
Ammonia-Nitrogen, monthly maximum	25 mg/L
Ammonia-Nitrogen, monthly average	10 mg/L
pH	6-9 std. units

OZONE SYSTEM DESCRIPTION

The ozone generation system consists of two separate skid mounted units each containing an air pretreatment unit, an ozone generator, and a stepped-up voltage transformer. Ozone from these two units is piped to the ozone contactor. The air pretreatment unit consists of an air compressor, an air cooling unit (called a refrigerant dryer), and a desiccant dryer. The purpose of the air pretreatment unit is to provide particle-free, dry air (-60°F dew point) to the ozone generators. Each generator was designed to provide an ozone dosage of 6 mg/L to the wastewater at the plant design flow rate of 1.5 mgd. However, ozone transfer rates of only 50 percent, as opposed to a 90 percent design value, are currently being achieved. The result is that a maximum ozone dosage of 9 mg/L, as opposed to 6 mg/L, is necessary. A schematic representation of the UTSD ozone system is shown in Figure 7.

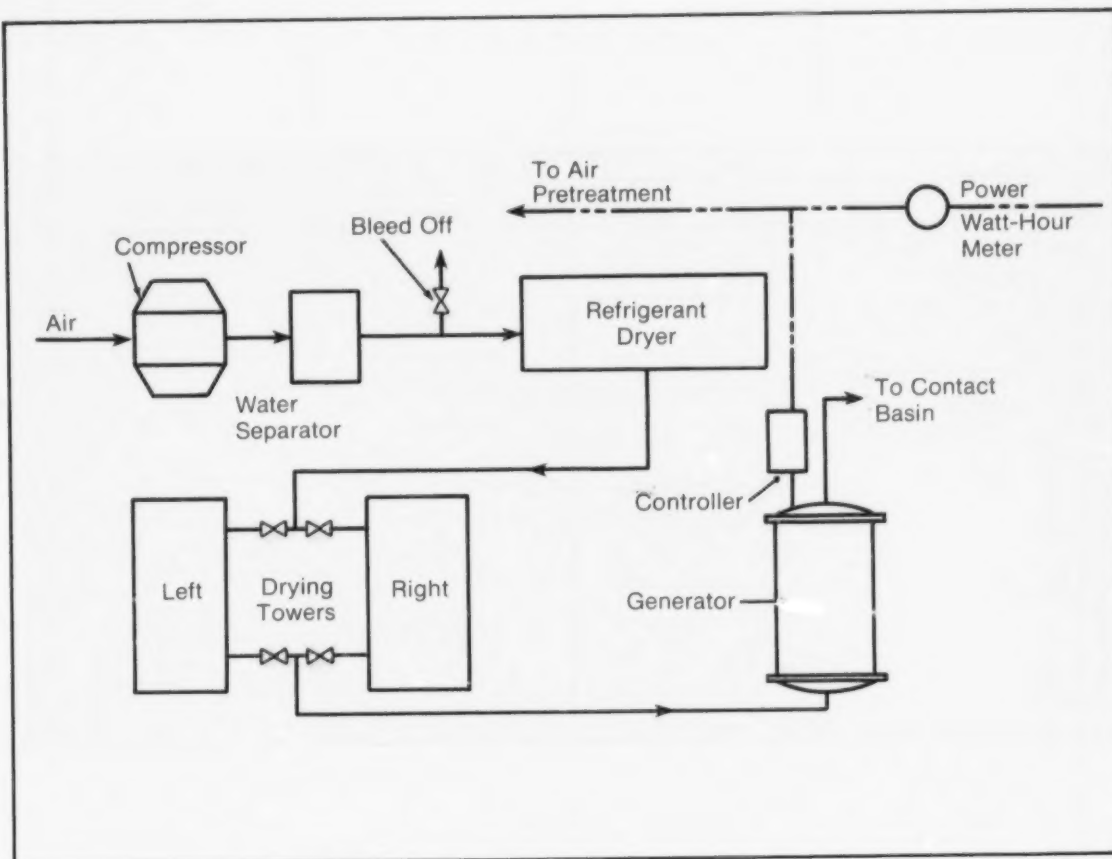


FIGURE 7 OZONE GENERATION SCHEMATIC DIAGRAM

Ambient air is compressed to 7.5 psig by a Nash Model L3 water ring compressor. The compressor operates at a constant speed and has an output of 94 scfm. A baffle separator is provided to separate the water and air. A bleed-off air valve is provided downstream of the baffle separator. A bleed-off valve at this point was determined to be necessary during the research project to enable the air flow rate to the drying towers to be controlled to prevent overloading of these units.

Compressed air is cooled to between 3.3°C and 5.6°C in a Zeks Model 9J refrigerant dryer in order to remove excess moisture in the air. The unit is designed so that the air dew point leaving this unit does not exceed 8.9°C. Refrigerant dried air is further dewatered to a dew point less than -51°C in a Kemp Model 100 UEA-1 absorptive dryer. The dryer uses molecular sieves and activated alumina as absorptive material. Dual towers are provided for continuous operation. Tower operation is cycled at 8-hour intervals to provide regeneration of one tower while the other is in use. Each tower is rated by the manufacturer to dry 78 scfm of air.

Ozone is generated by two Welsbach air-fed units, Model CLP-68F20L. Each generator is designed to produce 76 lb/day of ozone at a minimum concentration of 1 percent by weight, which provides a maximum ozone dosage of 6 mg/L at the plant design flow of 1.5 mgd. The generators are "horizontal" tube-type units, each containing 68 tubes. The generators are water-cooled using potable well water flowing at a rate of approximately 20 gpm. Power is supplied to the generator through variable voltage transformers. A controller assembly is used to adjust the voltage from the transformer to the generator, which controls the ozone generator output. The controller is designed for manual or automatic adjustment.

The ozone contact basin is located adjacent to the mixed media filters in the main control building. The ozone generation units are located on a mezzanine above the contact basin. The ozone contact basin is 4.25 ft wide, 38 ft long, and 12 ft deep, which provides an ozone contact time of 14 minutes at 1.5 mgd design flow. The first 27 ft of the ozone basin is divided into nine equally-sized compartments with PVC baffles. The baffles are placed to allow a vertical, serpentine flow pattern through the basin. A schematic of the ozone contact basin is shown in Figure 8.

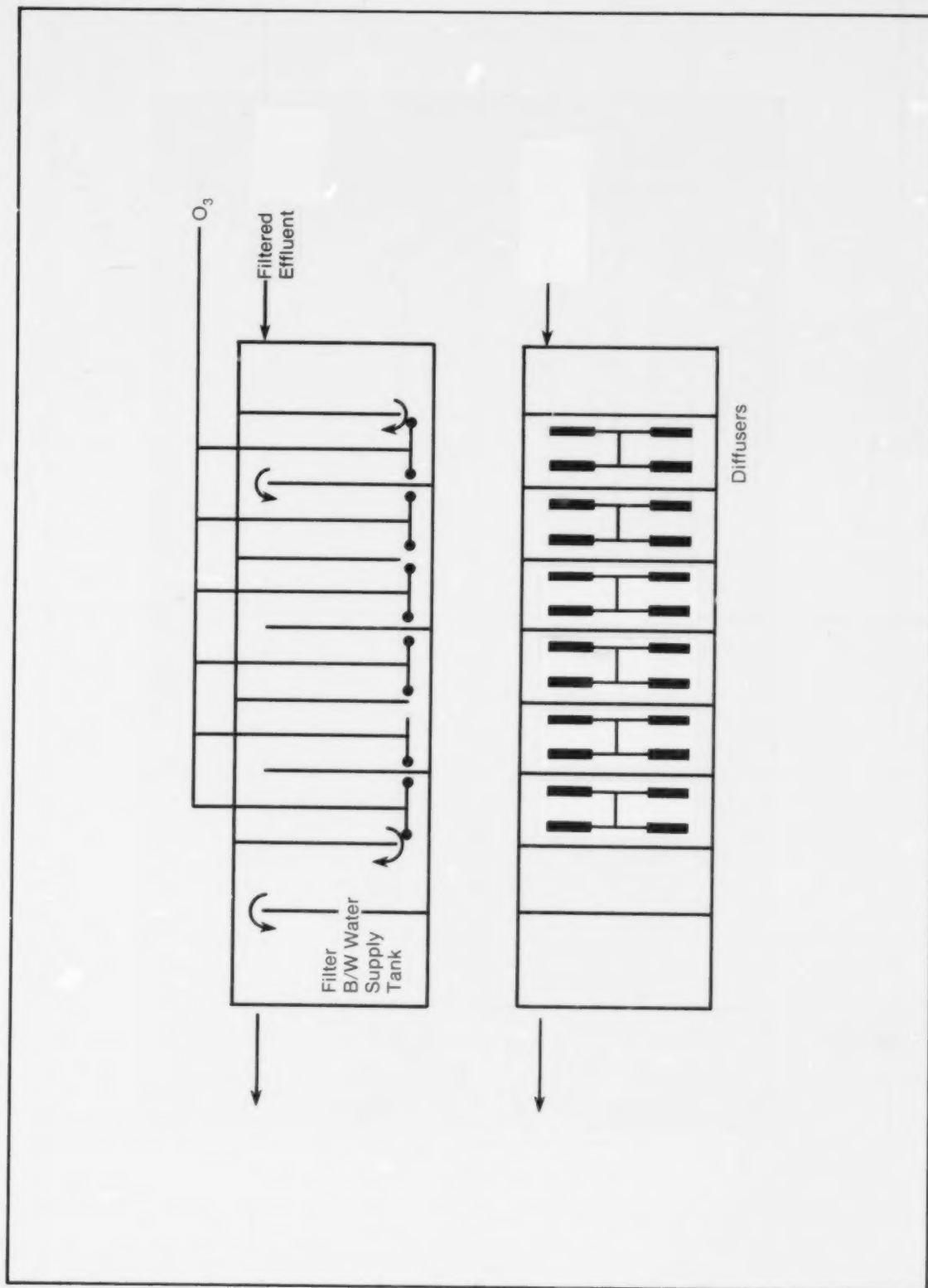


FIGURE 8 SCHEMATIC OF OZONE CONTACT TANK

The contact basin is covered with aluminum plates which are bolted in place. Hypalon gasket material is placed beneath all joints. In addition, silicone sealant is used to cover all exposed joints. Ozone laden off-gas from both the contact and backwash water storage basins is discharged through a roof-mounted exhaust fan. The fan provides a negative pressure in each basin to prevent ozone leakage into the main control building and/or offices. A water spray nozzle is located in the vent duct just above the tank cover to prevent foam from blocking the exhaust air flow.

Ozone is injected into the treated wastewater through porous stone diffusers. The diffusers are Kullendite, Model FAO 50 as manufactured by the Ferro Corporation. The diffusers are located in each of the nine baffled areas. Each diffuser is 2-1/2 in. in diameter and 24 in. long, and has an air permeability between 12 and 15 scfm/ft²/in. and a maximum pore diameter of 140 microns. Distribution piping consists of Type 304 Schedule 40 stainless steel piping with welded and threaded joints. Distribution of ozone to each compartment is controlled by nine individual valves.

The off-gas from the ozone contact basin is exhausted to a heat/catalyst ozone destruct unit. The ozone destruct system was designed by Emery Industries and includes an off-gas pre-heating unit, a proprietary catalyst, and an exhaust fan.

The system design inlet flow rate is 200 scfm at an inlet temperature of 50°C. The heating system is capable of elevating the temperature of this volume of off-gas to a maximum value of 300°F. At this temperature and gas flow rate the heat-catalyst system is designed to discharge a maximum residual ozone concentration of 0.1 ppm when the heat/catalyst inlet ozone concentration is 3,000 ppm or lower. The system is equipped with a variable temperature heating system and currently the unit is operated at a temperature of 160°F.

FACILITY OPERATIONS

Ozone System Control

Ozone dosage is controlled manually by adjusting the amperage of the operating generator. Amperage is adjusted by turning a rheostat control on the respective ozonator control panel. Dosage requirements are set based on the fecal coliform count in the ozonated effluent.

Start-up and Operational Problems

The system air compressors presently discharge more air (96 scfm) than is required (70 scfm). Currently, the excess air is "blown-off" to the atmosphere. A proposed modification is to change the pulley sizes on the compressor motors in order to reduce their operating speed and associated volume of air discharged. This will also decrease the horsepower required to run the compressors by approximately one to two hp. Plant personnel indicated that the compressors have generally been quite reliable.

When the ozone system was first started up the refrigerant dryer unit was overloaded. The cause of the overloading was traced to a problem with the water seal air compressor. The air compressor was starved for water and heated up; this in turn heated up the air to the point that the refrigerant dryer couldn't cool it down. Modifications have subsequently been made to the air compressor to prevent it from being starved for water, and since then the refrigerant dryer has been performing satisfactorily; however, it has been proposed by plant personnel that a spare refrigeration compressor be purchased.

Several problems have been experienced with the system's desiccant dryers. This is significant since efficient performance of the desiccant dryers is imperative for efficient performance of the total ozone system. When the ozone system was first started up, the ozone generators could not achieve their rated production level; it was determined that the primary reason for this poor performance was that "wet air" was being discharged from the desiccant dryers. The manufacturer replaced the desiccant material, and the generators subsequently performed well and met design ozone production levels. It was estimated that under normal operating conditions the desiccant would last three years. However, about one year later, ozone production decreased again because the dew point of the air from the desiccant dryer was too high. This occurred even though the ozone generators had been operating only about 50 percent of the time (i.e., six months). Consequently, the desiccant was replaced again, and once more ozone production improved.

Another problem also occurred with the desiccant dryers. It was observed that the desiccant heating elements were severely bent and twisted within the desiccant material. This caused overheating of the desiccant, improper desiccant regeneration, and short-circuiting of the heating elements. Since all of the desiccant must be removed from the tower to replace the heating

elements, correcting this problem was a very time consuming endeavor.

The desiccant dryer manufacturer was contacted by UTSD regarding these problems, and various reasons for the problems were discussed. One reason was related to the drying tower regeneration process. If the regeneration heating cycle is too long or the desiccant gets too hot, the desiccant material will "break-up" and lose its water absorption properties. It was determined that the regeneration temperature control thermostat had been set between 350°F and 450°F as per the original instructions from the manufacturer. The manufacturer recommends that the maximum temperature be set at 200°F. In addition, the manufacturer stated that it is important that the desiccant be "saturated" with water before the reactivation cycle begins, the reason being that during the heating cycle the heat will be absorbed by the water, if present, and not the desiccant.

It has been proposed by the plant's consulting engineer that the UTSD desiccant dryers be retrofitted with the equipment that is now considered standard equipment on the newer model desiccant dryers. This includes:

- A dew point indicator, recorder, and alarm that can be used to initiate the tower reactivation cycle when the desiccant is saturated with water, as indicated by a high dew point reading.
- An enclosure for the dryer reactivation heating elements so that elements cannot warp, and can be removed and replaced without removing the desiccant.
- Better controls on the tower heating circuitry to prevent excessively high regeneration temperatures.

These modifications should provide better control over the operation of the desiccant dryer and facilitate maintenance of the units. It is noted that when the second charge of desiccant failed, a sample of it was sent to the manufacturer for analysis. The results indicated higher than normal concentrations of sulfate, chlorine (or possibly chloride), and iron were present in the desiccant, which would contribute to premature desiccant failure (especially the iron). The source of these contaminants has not been isolated, nor has a definite solution for their removal been determined. Two potential sources are iron rust from within the system piping caused by a corrosive water vapor in the air, and iron coming directly from the water used as seal

water for the air compressors. Treatment of the air compressor's seal water may be required.

Each of the two ozone generators was designed to provide a 6 mg/L ozone dosage at a design flow of 1.5 mgd. This was dependent on an expected 90 percent ozone transfer efficiency in the ozone contact basin. However, based on test results at the plant, only a 50 percent ozone transfer efficiency is being achieved, so an ozone dosage greater than 6 mg/L is required to achieve adequate disinfection. It appears that a maximum dosage of 9 mg/L is necessary; and, to achieve this higher dosage, both ozone generators must be operated simultaneously. As currently constructed, this means that both air pretreatment systems must also be operated. Studies conducted in July 1979 by Mand I, Inc., Consulting Engineers, and the Upper Thompson sanitation district show that ozone transfer efficiencies typically range between 50 and 60 percent. The results of this study are reported in Evaluation of Pollution Control Processes - Upper Thompson Sanitation District, EPA-600/2-80-016. During this study, transfer efficiencies as low as 35 and as high as 70 percent were noted. At times, poor disinfection was also correlated with high TSS concentrations.

A stand-by electrical generator was provided to operate one ozone generation system. The electrical generator will not support operation of both ozone generators, so electrical controls are needed to "drop-off" one ozone generator if the stand-by generator is needed. If ozone production is not sufficient to achieve disinfection at that time, then the back-up calcium hypochlorite disinfection system must be used to supplement ozone disinfection.

On several occasions "generator flooding" (i.e., wet air supply to generator) occurred. This condition occurs when the air drying towers become saturated, causing the desiccant material in the towers to lose effectiveness as a drying agent. When it was suspected that the desiccant in the UTSD drying tower was ineffective, new desiccant material was ordered. The generator flooding problem was attributed to four major items:

- Continuous overloading of the air drying towers.
- Malfunction of the linkage in the tower switching mechanism.
- Refrigerant dryer failure.

- Low water flow to the water ring compressor due to plugging of an in-line filter that could not be detected due to improper placement of a pressure gauge.

These items have been corrected by installing an air-flow valve between the air compressor and the refrigerant dryer, and by installing a pressure gauge to indicate the water pressure to the water ring compressor downstream of the in-line filter.

The ozone piping at the UTSD was originally unplasticized polyvinyl chloride (UPVC) pipe. This pipe was not ozone resistant as originally claimed by the ozone manufacturer, and had to be replaced with stainless steel pipe. The stainless steel originally had some welded and some threaded joints. The threaded joints developed ozone leaks and subsequently were also welded. Since then no leakage problems have occurred with the ozone piping.

The ozone contacting system consists of an ozone contact basin, ozone diffusers, and scum skimmers. The ozone diffusers functioned satisfactorily during start-up, but eventually the seals deteriorated and the diffusers had to be replaced. UTSD personnel feel the diffusers should be inspected annually, which makes it necessary to have a back-up disinfection system.

Originally, the ozone contact basin was only partially covered and was not sealed. Excessively high concentrations of ozone in the basin off-gas necessitated covering and sealing the contact basin and venting the off-gas to the roof. The backwash water supply basin, which receives ozonated effluent from the ozone contact basin, also had to be vented. In addition, the vented off-gas had to be treated to destroy the ozone before it could be safely discharged to the atmosphere. Sufficient removal of the off-gas from both the ozone contact basin and the filter backwash supply basin has been a major problem at the UTSD plant, especially when the filters are backwashed and water is pumped out of the backwash supply basin. To solve this problem, it has been proposed that the ozone contact basin and backwash supply basin be isolated from each other, and that ozonated effluent not be directed to the backwash supply basin. To accomplish this, the following changes are proposed by the plant's consulting engineer:

- Modify filter effluent piping to discharge filter effluent directly to the backwash supply basin instead of the ozone contact basin.

- Install new influent piping to the ozone contact basin that originates from the backwash supply basin. Install the piping with water traps so no off-gas from the ozone contact basin can enter the backwash supply basin, and so the backwash supply basin will fill before water is directed to the ozone contact basin.
- Move the plant effluent discharge point from the backwash supply basin to the ozone contact basin. This requires that a new overflow weir be constructed at the end of the ozone contact basin.

Isolation of the ozone contact basin will confine ozone use to a small area within the plant, improve ozone control and treatment, and prevent ozone dispersment into the plant working environment.

A second source of ozone leakage is from the plant non-potable water supply system which utilizes ozonated wastewater. When an ozone residual is present in the wastewater discharge, ozone is released at various outlets within the plant's non-potable water system. Further refinement and fine tuning of the ozone feed system may allow disinfection standards to be met without producing an ozone residual that enters the non-potable water system. Modifications (i.e., non-ozonated water source) to the plant's non-potable water system may be necessary to prevent the potential distribution of ozone throughout the plant's working environment.

The ozone destruct system is a heat/catalyst system. The off-gas is heated to a maximum temperature of 300°F, and the ozone in the off-gas is absorbed on the catalyst. The ozone destruct unit was designed to reach 1 ppm ozone normally, and as low as 0.1 ppm if necessary. To date the system has not achieved these levels, but the manufacturer (Emery Industries) has been very responsive in addressing the problems and appears committed to resolving them.

Modifications proposed by the plant's consulting engineer consist of removing the existing 8 in. x 14 in. off-gas duct work and replacing it with 12 in. diameter stainless steel duct, installing a foam suppressing unit (demister), installing a new off-gas flow meter to accurately measure the off-gas flow rate, and installing a new off-gas vent fan to pull the off-gas from the ozone contact basin at a greater suction pressure.

One ozone meter is currently used to monitor the ozone concentration in the plant's working environment. This meter is usually located in the plant office/lab area. The meter must be routinely cleaned, checked, and calibrated by the plant staff. Periodically, the meter must be sent to the factory for annual servicing. The existing ozone monitor is portable, but one unit is insufficient to monitor both the office/lab working area and the working area in the treatment complex where the ozone contact basin is located. It is proposed by the plant's consulting engineer that a second ozone meter be purchased so that both areas can be monitored, and a third meter be purchased as a back-up unit when a unit is sent to the factory for servicing. It has also been suggested that the meters be tied into a recorder/alarm system that will activate when the meter-reading reaches a pre-set level.

Operations and Maintenance Staff

Both laboratory and plant operations staff appear to be very competent. Personnel have shown active participation and interest in the ozone disinfection system. The number of personnel and the training they received also appear to be adequate for successful plant operations.

MAINTENANCE

Maintenance requirements for the system consist primarily of inspecting and cleaning the ozone generator units. It is estimated that 180 man-hours per year (1.2 man-hours per day) are required for operation and maintenance. Since the ozone generating equipment is currently down, a maintenance schedule was not in effect.

OPERATIONS AND MAINTENANCE COST

Components of the ozone system include the air pretreatment equipment, generators, contact basin and diffusers, and the off-gas destruct unit. The 1979 capital cost of this system was \$341,000, or 11.5 percent of the total plant cost. Approximately \$160,300 of the capital cost was for equipment, including: air pretreatment equipment, ozone generators, diffusers, piping, ozone monitoring equipment, and the off-gas destruct unit. Materials and labor utilized for construction amounted to \$48,700. The cost for associated piping, electrical systems, equipment controls, and site preparation was \$132,400.

When the ozone disinfection system was operating, approximately \$1,000 per year was required for materials. Most of this cost was for the purchase of electrode tubes and fuses. Manpower was required for daily inspection of the air pretreatment and ozone generation equipment. An additional 180 man-hours per year were necessary for cleaning the ozone generator units. These activities required an average of 1.2 man-hours per day, which resulted in an annual 1979 cost of \$2,300. Determination of the power cost for ozone generation was difficult since the unit was not continuously operated. Values obtained during intermittent operation were used to extrapolate power costs. Since an off-gas destruct unit has been recently added to the system, the plant power records do not reflect this additional cost. Based on an 8 kw demand for the destruct unit, a power cost was estimated for off-gas destruction. The power cost for the entire ozone system was estimated to be \$8,900 annually. When the cost of materials, labor and power were combined, the annual operational cost totaled \$12,270. A detailed O&M cost breakdown is given in Table 5. Costs shown are based on continuous operation.

Table 5

Table 5

Upper Thompson Sanitation District
Ozone System Cost Sheet

O₃ Generation Rate = 22 kg/d at 9 mg/L
FCI = \$341,500

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power (including air pre- treatment and cooling water pumping)	35.28	3.25	115
Operating Labor (.087 MY) (including repair and labor supervision)	(Well water supply)		29
Repair Materials (0.3% FCI)			12
Supplies (10% O.L.)			<u>3</u>
Total Operating Cost			159
<u>Overhead Cost</u>			
Insurance			42
Amortization (7% at 20 years)*			<u>401</u>
Total Overhead Cost			443
TOTAL OZONE COST ¢/kg (¢/lb)			602 (272)

MY, Man Year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor

*Actual numbers are unavailable and these percentages were
taken from Opatken, E.J., EPA-600/9-79-018, 1979.

FRANKFORT WASTEWATER TREATMENT PLANT FRANKFORT, KENTUCKY

GENERAL

Frankfort is located in the northwestern portion of Kentucky, approximately 30 miles west of Lexington on Interstate 64. A site location map is shown in Figure 9. On 4 March 1971, the Kentucky Water Pollution Control Commission advised the City of Frankfort that the existing primary wastewater treatment plant had to be upgraded to provide secondary treatment in order to prevent further pollution of the Kentucky River. Construction of the secondary treatment facility was initiated in 1978, plant operation began in April of 1980, and the ozone system began operating in October of 1980. The plant was visited on 22 March 1982.

The treatment process includes grit removal, two oxidation ditches, final clarification, ozone disinfection, and sludge dewatering via a filter press. A simplified plant flow diagram is shown in Figure 10. Presently the plant receives an average daily, dry weather flow of 4.5 mgd, with wet weather flows of approximately 7 mgd, and peak flows of 10 to 12 mgd. Design flows, organic loading, solids loading, and dry and wet weather wastewater characteristics are shown in Table 6. Current and projected treatment requirements for the Frankfort Wastewater Treatment Plant are shown in Table 7.

OZONE SYSTEM DESCRIPTION

During conceptual design of the disinfection system for the Frankfort Wastewater Treatment Plant, several factors were considered which ultimately led to a decision to use ozone for disinfection rather than chlorine, UV, or any other alternative methods available. It was decided that ozone would be a more effective disinfectant than chlorine due to its ability to inactivate viruses, its lack of appreciable ozone residual, and its ability to add further dissolved oxygen into the effluent stream.

The state of Kentucky has a maximum limit of 0.5 mg/L of residual chlorine in any effluent discharged to a surface stream. It was therefore felt that the permit requirement for fecal coliforms of 200 colonies per 100 ml could not be consistently achieved without heavy chlorination followed by dechlorination and possibly a post-aeration step. A detailed economic analysis

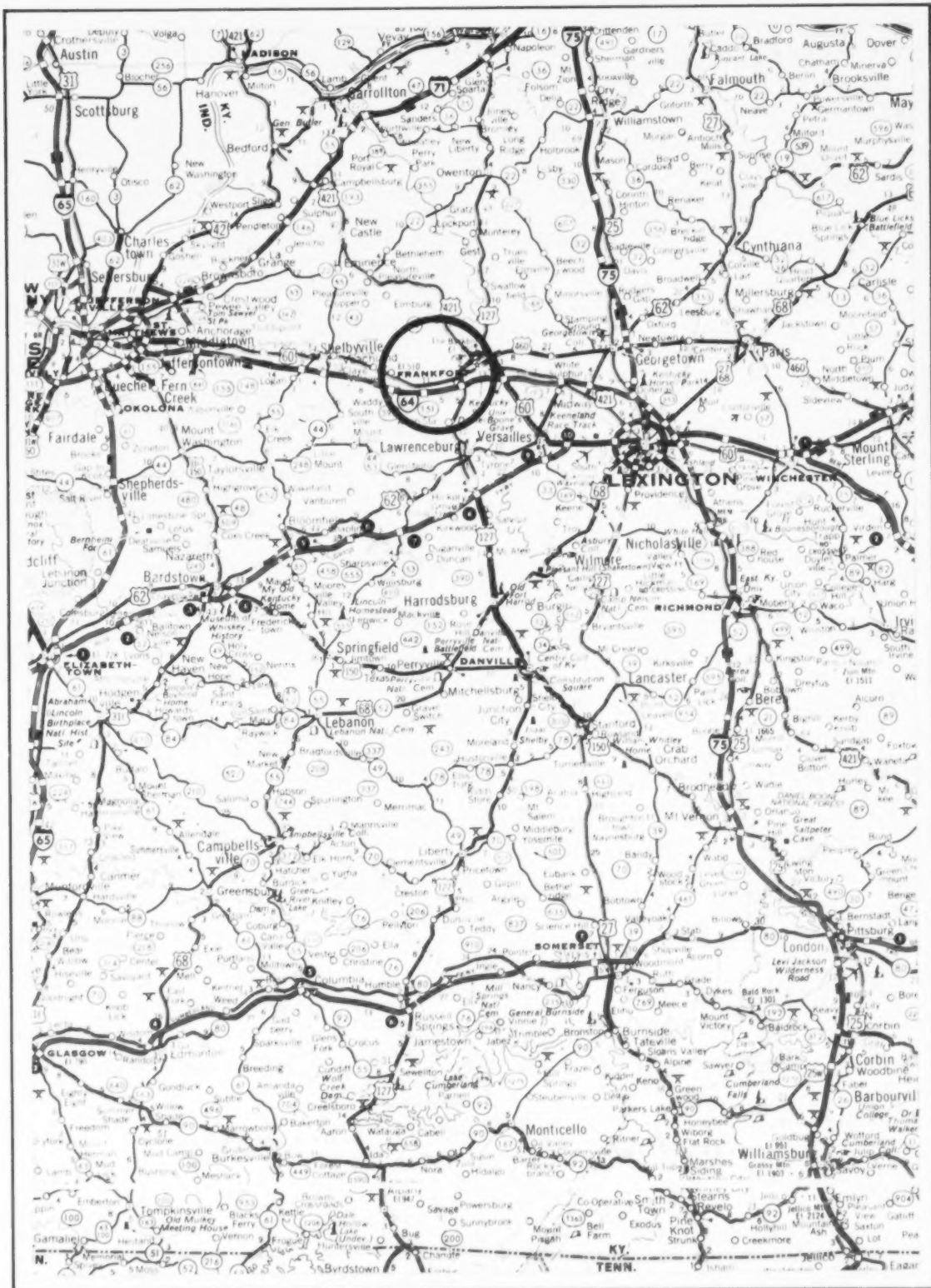


FIGURE 9 PLANT LOCATION MAP

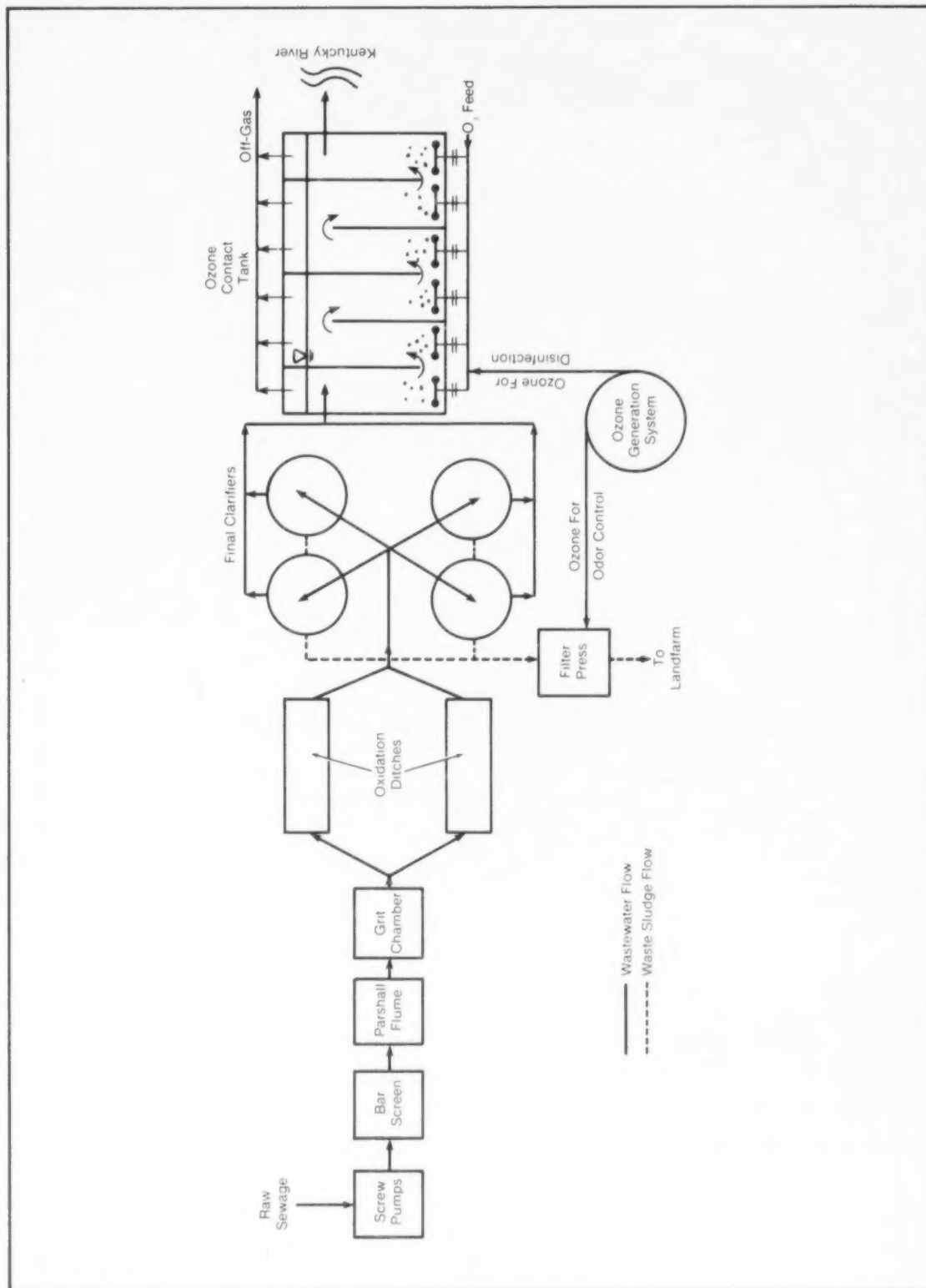


FIGURE 10 PLANT FLOW DIAGRAM

Table 6

Design Paramaters
Frankfort Wastewater Treatment Plant

Dry Weather Flow	6.4 mgd Maximum
	4.3 mgd Average
Wet Weather Flow	11.0 mgd Maximum
	8.9 mgd Average
Organic Loading	8,600 #BOD ₅ /day
Solids Loading	10,000 #TSS/day
Dry Weather Waste Strength	240 mg/L BOD ₅
	280 mg/L TSS
Wet Weather Waste Strength	98 mg/L BOD ₅
	114 mg/L TSS

Table 7

NPDES Discharge Limitations
Frankfort Wastewater Treatment Plant
Frankfort, Kentucky

Parameter	Current Limits	Projected Limits
BOD ₅	30 mg/L	10 mg/L
TSS	30 mg/L	10 mg/L
Fecal Coliform	200/100 ml	200/100 ml
NH ₃ -N	20 mg/L	1 mg/L
D.O.	4 mg/L	8 mg/L
pH	6.0 - 9.0	6.0 - 9.0

of both disinfection strategies indicated that ozonation would be the most cost-effective alternative.

In addition, the City felt that a properly-designed ozonation system was less hazardous to operating personnel and adjacent residential and/or commercial areas than a chlorination system. Since initial start-up of the Frankfort plant, there has only been one incident in which an operator was seriously exposed to ozone. The accident was not equipment or piping related, but instead was due to operator negligence; however, no serious injury occurred.

A flow schematic of the Frankfort ozone system, which indicates the major operational units, is shown in Figure 11. A typical ozonation system has five basic components:

- Air/gas handling unit.
- Air/gas preparation unit.
- Ozone generator.
- Ozone contactor.
- Ozone destruct unit.

At the Frankfort plant, an air system was selected due to the plant requirement for less than 600 lbs of ozone per day and the non-availability of an on-site oxygen supply.

Standard air preparation equipment is utilized at the Frankfort Wastewater Treatment Plant; this includes freon air refrigerant units in series with heat-reactivated, catalytic adsorption air driers.

Water-cooled ozone generators were selected to be installed at the Frankfort plant. This was done to allow recovery of the waste heat for heating the plant maintenance shop, sludge processing room, and ozone generation room. Three Emery EG-200 ozone generators were installed. Each has a capacity of 575 ppd.

The plant's two ozone contactors were designed to provide at least 90 percent transfer of the ozone gas. The two contactors have a side water depth of 18 ft and are plug flow units run in parallel. Fine bubble diffusers are utilized to achieve a high degree of turbulence, which is necessary for efficient gas liquid mixing and adequate disinfection. A schematic diagram of the contactors used at the Frankfort plant is presented in Figure 12.

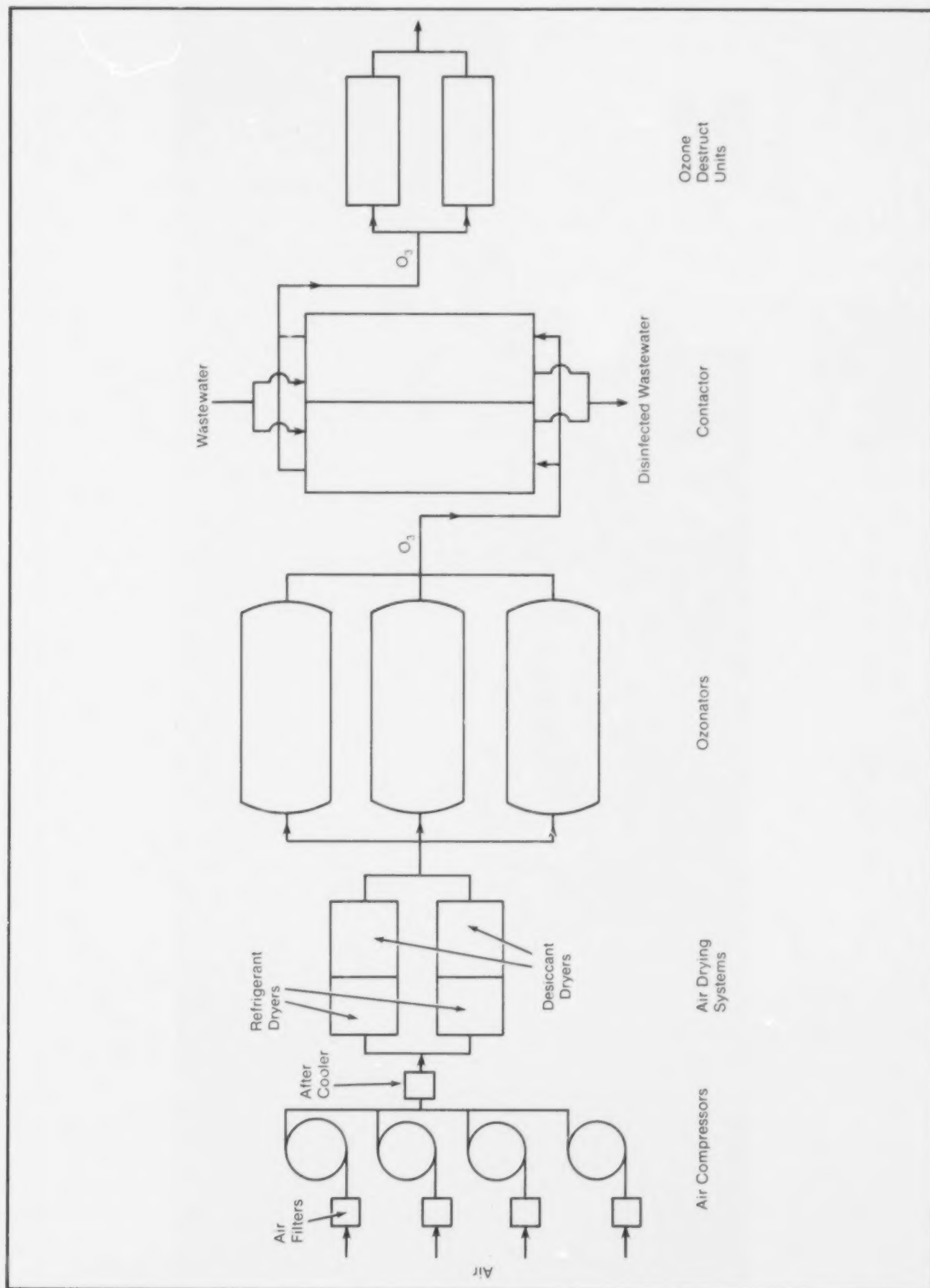


FIGURE 11 SCHEMATIC OF FRANKFORT OZONE DISINFECTION SYSTEM

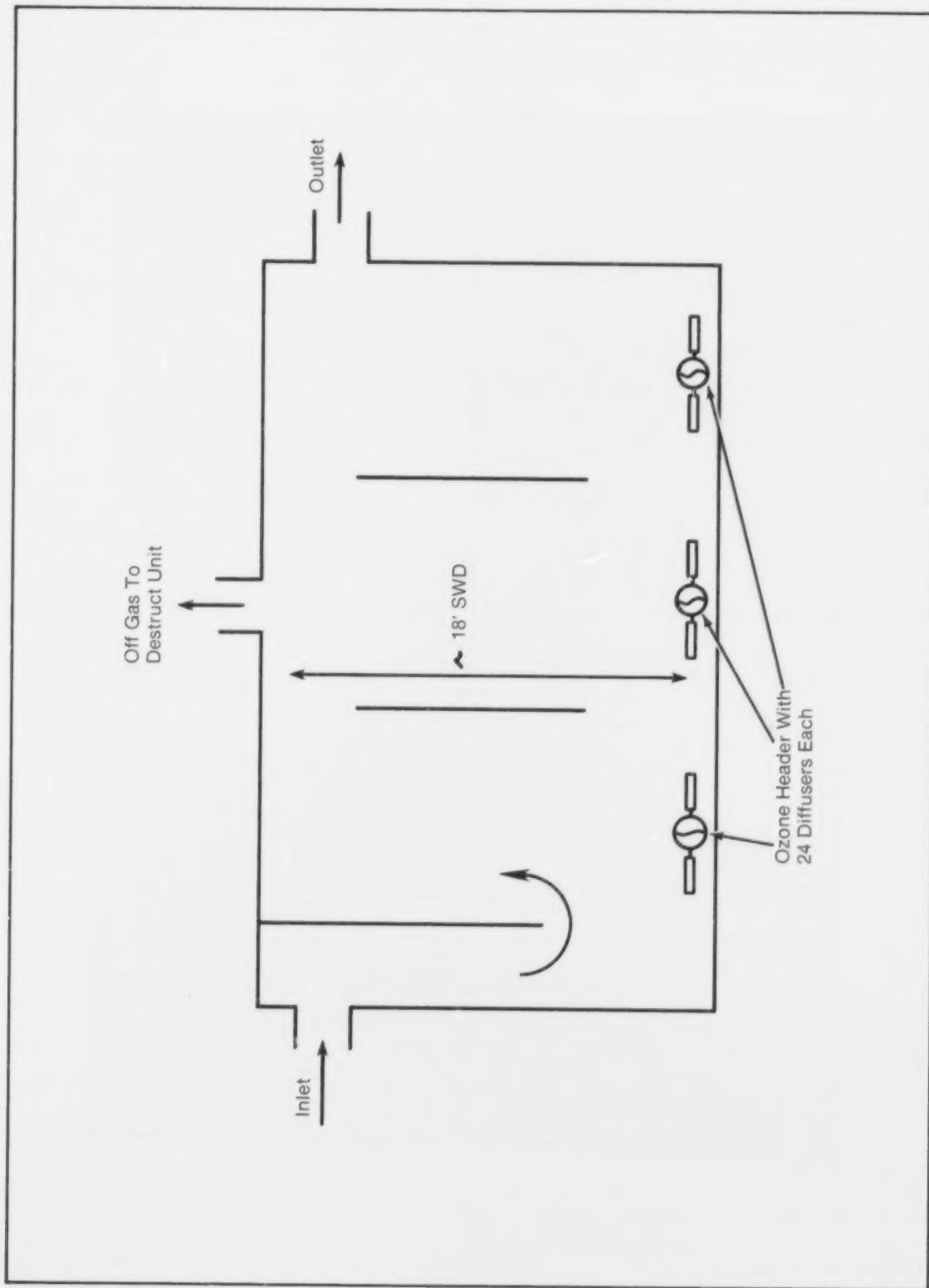


FIGURE 12 OZONE CONTACTOR TANK

Because ozone is a toxic gas, the contact chamber must be gas-tight. If 90 percent of the ozone gas is utilized, the off-gas from the contactor will still contain approximately 10 percent of the concentration applied. Thus, if a feed gas with 1.0 percent ozone concentration were applied, the off-gas from the ozone contactor would contain 0.1 percent or 1,000 ppm of ozone.

At that point, not only are personnel subjected to a toxic gas, but equipment and structures in the immediate area are exposed to the corrosive effect of ozone. At Frankfort, an ozone destruct unit composed of a catalytic converter and air heating system is utilized to reduce the ozone concentration of the off-gas to 0.3 to 0.5 mg/L. A schematic of the ozone destruct units is shown in Figure 13.

Major ozone generation equipment installed at the Frankfort Wastewater Treatment Plant is listed in Table 8. The system was designed such that all system piping could accommodate any combination of air preparation or ozone generation units in order to allow for routine repair or component failure. Piping from the air preparation system to the ozone generators and all cooling water piping is of welded steel construction. All ozone gas piping is welded stainless steel for corrosion protection and safety purposes.

FACILITY OPERATIONS

Ozone System Control

The Frankfort ozone system employs a single pass, air feed generation system in which air is compressed, cooled, dried, converted to ozone, and diffused into the effluent for disinfection purposes. Feed air is filtered as it enters the air compressors, which are non-internally lubricated in order to prevent oil vapors from being carried over to the absorptive dryer and impairing the water absorptive capacity of the desiccant. Filtered air is compressed to approximately 15 psig to force it through the system.

Compressor aftercoolers (water-cooled) are utilized to reduce the air temperature prior to the air entering the refrigerant dryers. By removing the heat (due to compression), the air temperature is lowered from approximately 200°F to 80°F, and thus smaller refrigeration units can be utilized. The compressed air passes through the refrigerant dryer, where liquid freon absorbs additional heat, thereby reducing the temperature of the air to between 33 and 45°F. The cooled, compressed air loses 98 to 99 percent of its condensed moisture, thereby reducing the

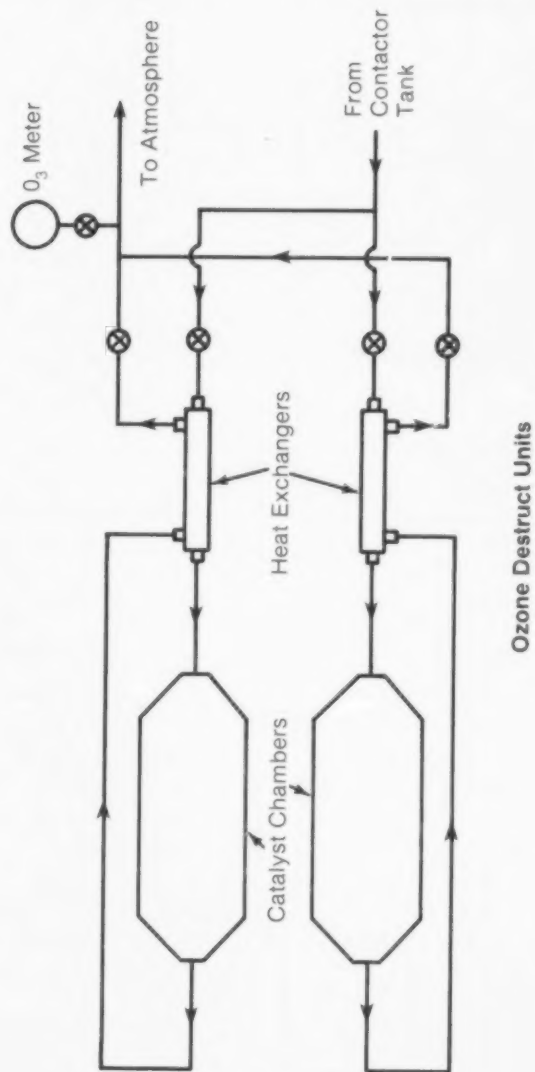


FIGURE 13 OZONE DESTRUCT UNITS

Table 8

Major Ozonation Equipment
Frankfort Wastewater Treatment Plant

Component	No.	Design	Manufacturer
Air Compressor	4	130 scfm at 15 psig	Gardner Denver
Refrigerant Dryer	2	390 scfm to 40°F	Lectrodryer
Desiccant Dryer	2	355 scfm to -60°F	Lectrodryer
Ozonators	3	575 #O ₃ /day at 1.5%	Emery
Ozone Diffusers	144	355 scfm (Rod Type)	Emery
Ozone Destruct Unit	2	99% Reduction	Emery
Dew Point Monitor	1	-30°C to -80°C	Panametrics
Air Flow Meter	2	Turbine Type	ITT Barton
Ozone Monitor (H.C.)	1	UV Type	Dasibi
Ozone Monitor (L.C.)	2	UV Type	Mast
System Controls	---	---	Fischer & Porter

pressure dew point of the gas to 35°F. This cold air, still laden with water, must be dried further to a dew point of -60°F. This is accomplished by passing the air through a bed of activated alumina desiccant.

Because ozone production is designed to be continuous, dual drying towers are used. While one tower is drying, the other is being reactivated. Reactivation involves the evaporation of trapped water from the desiccant, and a subsequent air purge of the tower to remove absorbed water. Electric heaters distributed throughout the desiccant provide the heat for this reactivation process. A small amount of dried air leaving the dryer is recirculated to provide a constant purge of moisture from the tower during the reactivation cycle. The recirculated, dried air stream represents approximately 5 percent of the total air flow into the drier. Air leaving the desiccant dryers has a dew point of -60°F and is ready to be used as feed gas to the ozonators.

The dried air dew point is continually monitored before the air enters the ozone generators. Pretreatment for reducing moisture in the compressed feed gas stream is essential. Moisture can combine with oxides of nitrogen formed in generators to produce nitric acid. In addition, ozone production is very dependent upon the dryness of the air feed gas; should the dew point rise above -40°F at the Frankfort facility, an alarm sounds to alert the operator.

The generation of ozone at the Frankfort plant is accomplished via the corona discharge method. Each ozone generator is composed of 109 evenly-spaced tubular units (see Figure 14). The outer stainless steel tubes serve as the outer electrode and are enclosed in a cooling water jacket. Centered inside each stainless steel tube is a pyrex glass tube which serves as the dielectric element. The inner electrode is a stainless steel screen, physically secured, but not attached to the inner surface of the dielectric. Electrical current is applied to the inner electrode, with the resultant voltage jumping through the glass dielectric and grounding itself on the outer electrode. In this way, an electrical corona is established and the generation of ozone occurs. Feed air flows between the glass dielectric and the outer stainless steel tube, with a small additional amount of feed air flowing through the center of the dielectric. Ozone is formed in the discharge gap between the inner electrode and the outer electrode. The ozone generator uses standard 60 Hz power and is a voltage-controlled unit, with ozone production dependent upon input voltage to the transformer/reactor.

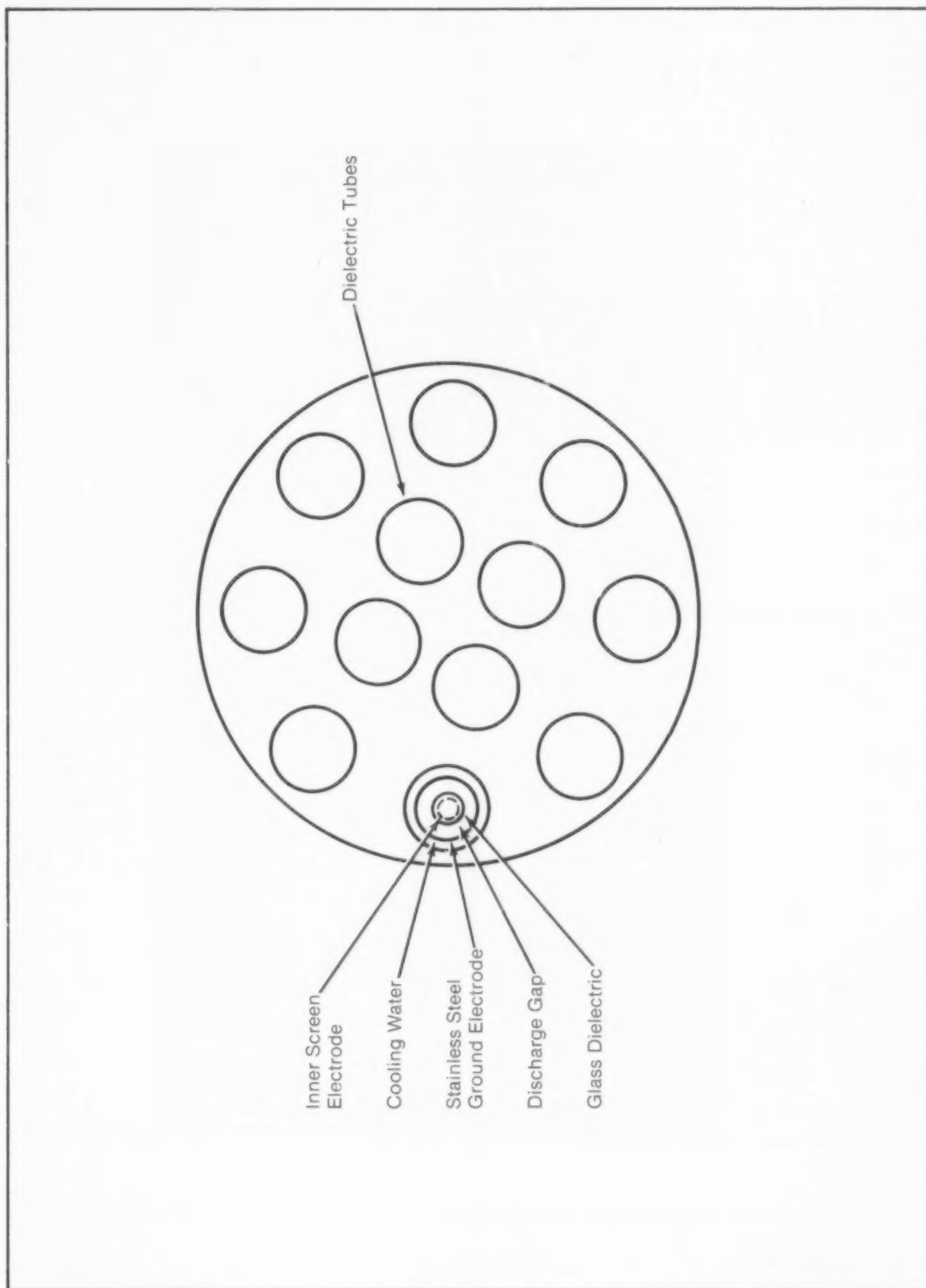


FIGURE 14 OZONE GENERATOR SCHEMATIC

Ozone-enriched air at approximately 1.5 percent ozone by weight is distributed from the generators to porous ceramic diffusers mounted on the bottom of the contact basin by means of a manifold. The ozone feed-gas flow-rates are monitored by individual flow meters at each of the six basin entry points. In the ozone contactor a certain portion of the ozone-enriched air rises to the water surface and concentrates in the head space of the contact chamber.

This off-gas may contain up to 1,000 ppm of ozone and must be vented from the gas-tight chamber. Before venting to the atmosphere, however, the ozone-laden gas passes through an ozone destruct unit. The unit is designed such that spent gas first enters an economizer (i.e., heat exchanger) where it is preheated by the air leaving the unit. As the preheated air enters the catalyst chamber, it is further heated to 300°F and subsequently flows over a proprietary catalyst which removes the ozone. The exhausted air from the catalyst chamber is then recycled back through a heat exchanger in the economizer to preheat the incoming air and reduce the energy consumption of the unit. The air is then vented to the atmosphere.

The closed-loop cooling water/heat recovery system circulates cooling water to the ozonators and the compressor aftercoolers. During the summer months, a heat exchanger is used to remove waste heat from the system. During the winter months, the heat exchanger is bypassed and water is diverted to heat recovery coils located in the maintenance shop, the sludge room, and the ozone room.

Ozone production varies proportionally to the wastewater flow in order to provide the desired ozone dosage rate. In addition, the flow of air through the ozonation system can be controlled automatically by a set-point controller and its related sensors, or manually with start-stop, push-button switches. If the flow of air is run automatically, one compressor is on-line at all times. When additional air is required as determined by the ozone dosage set point and the influent wastewater flow, additional compressors are automatically brought on-line. The ozone generators operate from a single-point controller located on the central control panel. The controller dosage range is 0 to 20 mg/L of ozone. The set-point controller and the associated instrumentation is programmed to calculate and record the actual ozone dosage, and to adjust generator voltage as required to maintain the desired set point. Although this is normally automatically regulated, the power controller can be manually operated from between 20 and 100 percent of the generator's capacity.

The ozonation system is equipped with annunciators wired in the circuitry to sound an alarm should a failure or system upset occur. A listing of the operational occurrences that activate an alarm are listed as follows:

- High Ozone in Room.
- High Dew Point.
- High Pressure in Contactor.
- Low Gas Pressure.
- High Cooling Water Temperature.
- High Ozone After Destruct.
- High Explosive Limit.
- High Feed Air Pressure.
- Low Cooling Water Flow.
- Low Power to Generators.

Start-Up and Operational Problems

Start-up of the Frankfort Wastewater Treatment Plant was initiated in April 1980. At that time the decision was made not to start the ozone system until all the wastewater treatment processes had been debugged. In June 1980 the ozone system was ready to be started. After some false starts and long waits for system components, the ozone system was ready for performance testing in October 1980. During the performance testing, monitor system corrections were completed. The Frankfort Sewer Board accepted the ozone system in February 1981. Some of the problems encountered during start-up included: design deficiencies in the cooling water system; improperly sounding alarms; inconsistent ozone monitor readings; ozone feed oscillations due to faulty input signals; improper installation of the economizer in the ozone destruct unit; a bad charge of desiccant in the desiccant dryers; and faulty air-compressor check valves. Each of these start-up problems and their resolutions are discussed in the following paragraphs.

The closed-loop cooling water and heat utilization system consists of a 300-gallon cooling-water holding tank, three pumps, one frame-type heat exchanger, and associated controls. Soon after start-up, corrosion problems were experienced in the closed-loop system due to a faulty air release port which was drawing air into the system. As the cooling water was being aerated, scale and corrosion particles formed and subsequently plugged the cooling water inlet ports in the bottom of the ozone generators. This in turn prevented proper cooling of the dielectric tubes and resulted in frequent breaking and damaging of the

dielectric tubes due to overheating. The problem was corrected by replacing the air relief valve and adding corrosion prevention chemicals to the cooling water. Since these measures were taken, no related operational problems have occurred.

Improperly sounding alarms also hampered start-up of the ozone generation system. Alarms for shutting down the ozone generators due to the stoppage of cooling water circulation were found to be faulty. These flow-actuated alarms would stick open or close due to rust-particle fouling, and they were also improperly installed. Once the corrosion problem was resolved, as discussed in the previous paragraph, and the flow sensors were reinstalled, the problem was corrected. In addition, the low pressure alarms in the ozone generator gas system were improperly sounding. This problem was attributed to ozone destroying the diaphragms in the pressure alarms, and was corrected by the manufacturer by simply replacing them.

Fluctuating ozone readings also hampered efficient start-up of the ozone system. It is believed that faulty readings were caused by insufficient cleaning of ozone meters and system voltage fluctuations. (System voltage fluctuations are discussed in the following paragraph). Ozone meters were carefully monitored during start-up, and associated problems were resolved by increased maintenance and cleaning of the ozone meters and correcting the voltage fluctuation problem. This problem was very crucial because the ozone monitors control the ozone generation system and, if not properly operating, they can severely affect the performance of the disinfection system.

Large and irregular voltage surges in the ozone system resulted in damaged circuit boards, dielectric tubes, and ozone monitors. These large voltage surges were found to be created by the ozone dosage control loop. Large hydraulic surges were created in the collection system due to the on-off operation of system pumping stations. As these large hydraulic surges passed through the wastewater treatment plant, the flow-proportional ozone dosing system fluctuated according to the irregular flow pattern. Consequently, as the ozone generator voltage was rapidly increased and decreased, voltage surges were created in the electrical system and resulted in the previously discussed electrical problems. The situation was corrected by installing a new pumping station, as well as a control transformer, to dampen the voltage fluctuations prior to the ozone system control panel. Since these modifications have been made, similar operational problems have not been encountered.

The off-gas economizer, which preheats the air entering the catalytic destruct unit, was installed backwards. For this reason, the ozone in the off-gases was not being removed. The problem was solved by shutting down the system and re-installing the economizer properly.

During start-up, the media in the desiccant dryers had to be frequently changed. The first desiccant charge was found to be bad as delivered from the factory. The second charge couldn't produce a sufficiently low dew point and was subsequently replaced. Finally, the third charge seemed to work; however, two electrical heating elements burned out for an unknown reason. The desiccant and heating elements were subsequently replaced by the manufacturer and have operated properly since.

During start-up it was discovered that the compressors were equipped with improper check valves. When the compressors were shut down, the check valves slammed shut and forced the blowers to start running backwards, which ultimately caused the check valves to disintegrate and subsequently be sucked into the blower, causing damage to the impellers. In addition, the seals in the blowers quickly wore out following start-up and had to be replaced. The compressor manufacturer subsequently installed sturdier check valves and seals, which solved the problem. Since the Frankfort ozonation system was a site-specific one, the manufacturer of the ozone generators was responsible for the installation and start-up of all the equipment in the ozonation system. Thus, while many of the start-up problems encountered were actually problems related to various auxiliary pieces of equipment, the ozone manufacturer was still responsible for correcting the operation of these units.

The Frankfort ozone system has been operating for approximately two years. The operational problems that have occurred since start-up are discussed herein. These problems have required the attention of both the operating personnel at the Frankfort Wastewater Treatment Plant and the supplier of the ozonation system. One operational problem that occurred was related to the operation of the desiccant drying system. The desiccant drying tower was allowing improperly-dried air to enter the ozone generator. Consequently, nitric acid was being formed, causing dielectric failures. The cause for the poor air quality was attributed to deteriorated desiccant and a broken mount for an internal dryer heater switch. Rather than clean the generator completely, at that time it was decided to wait one month when the regularly scheduled ozone generator maintenance was to be performed. This proved to be a bad decision because within two

days, six additional dielectrics were broken. The ozone generator was subsequently cleaned and brought back on-line.

A second operational problem that was encountered concerned the ozone concentration monitor. This monitor measures and controls the ozone concentration from the generators. This instrument is extremely important due to its feedback role in the automatic ozone production control sequence. The instrument is extremely susceptible to fluctuations in readings due to dirty internal parts, and it requires continuous recalibration.

Another operational problem relates to the purge air filter on the desiccant dryers. As the towers are heating up for reactivation, recirculated purge air is required to carry out the wet air. Desiccant dust often clogs the filter at a very rapid rate, which necessitates filter cleaning at frequent intervals. Some smaller problems also exist within the ozone destruct units. The destruct units have electrical contacts which turn the electrical heaters on and off in order to maintain a 300°F operating temperature. These contacts have burned-out due to over-usage. Plant personnel are currently investigating using a different type of heater control.

After approximately 2 years of operation, plant personnel feel that there are two minor design areas which could have been improved upon. The first such area relates to the construction and/or design of the entrance hatches into the disinfection chamber. The existing hatches are stainless steel plates, which are secured to the concrete ozone contact tank with stainless steel bolts. The plates were originally installed with silicone rubber gaskets between the concrete and the plate. Two problems exist with this design. First, the stainless steel bolts have a tendency to seize up, with the stainless steel nuts making removal of the hatch very difficult. A more serious problem exists, however, because the concrete tank surface is not level and, therefore, the gasket material cannot be compressed tightly enough to stop gas from leaking out of the contact chamber. This design problem was corrected by installing a second half-moon shaped gasket. The second design, or construction error, is related to compressor noise. Air compressors are inherently noisy and provisions should have been made in the design to reduce noise levels to safe and comfortable levels. The noise level in the ozone generator room is currently between 90 to 100 db, which is not high enough to cause hearing damage if exposure times are less than a half hour. However, this level of noise is still very annoying, even if the operator only has to stay in the room for a short time.

Operations and Maintenance Staff

When the Frankfort operators were first introduced to the ozone disinfection system, they all felt the system was too complex to operate. With the manufacturer's assistance, however, these operational fears were put to rest and before long each operator felt very comfortable with the operation of the ozone system.

Plant personnel feel these operational problems have resulted in increased operator knowledge and operational know-how about the ozone system; the inconveniences encountered have been minor compared to the overall benefits derived from the ozone system.

Effluent characteristics for the Frankfort Wastewater Treatment Facility are summarized in Table 9. The plant's average daily flow of 4.03 mgd is effectively disinfected, via ozone treatment, down to a fecal coliform count consistently below 200 colonies per 100 ml. At present, the ozone dosage rate averages 6 mg/L. Plant personnel believe their ozone disinfection system provides a clean, aerated, and non-toxic discharge stream to the Kentucky River, and to date has lived up to its design expectations.

Table 9

Effluent Characteristics
Frankfort Wastewater Treatment Plant
October 1980 - October 1981

Average Flow	4.03 mgd
Average Effluent BOD ₅	7.0 mg/L
Average Effluent TSS	8.6 mg/L
Fecal Coliform Count	200/100 ml
Ozone Dosage (Applied) Range	5 to 8 mg/L

MAINTENANCE

Maintenance at the Frankfort Wastewater Treatment Plant is divided into four distinct categories: daily, weekly, monthly, and semi-annually. On a daily basis the operators read every pressure gauge, flow gauge, temperature gauge, hour meter, and strip chart recorder once every three hours. If something irregular is discovered, action is taken immediately to solve the problem. Weekly, monthly, and semi-annual preventive maintenance checks are also made on equipment, using maintenance sheets similar to those shown in Exhibits 1 through 5.

A relatively small but adequate spare parts inventory is maintained. Few spare parts are required since each system component was provided with a back-up unit. Therefore, if a component malfunctions, the spare is brought on-line while the other unit is being repaired. The spare parts inventory is presented as follows:

- Blower Bearings
- Dielectric Tubes
- Blower Belts
- Tube Spring Spacers
- Desiccant Dryer Low Temperature Gauges
- Stainless Steel Wires
- Dryer Solenoid Valves
- Site Glass
- Air Filters
- Contactor Ceramic Diffusors

OPERATIONS AND MAINTENANCE COSTS

Major equipment costs for Frankfort's ozone disinfection system are presented in Table 10. Detailed ozone production costs are presented in Table 11. It should be noted that where actual costs were unavailable, percentages were used from the indicated reference. Operating labor costs represent the plant supervisor's best estimate of hours and the calculated average employee's salary.

Exhibit 1
PREVENTIVE MAINTENANCE SCHEDULE

UNIT NAME Air Compressors UNIT NO.

		FREQUENCY					
		D	W	M	S	A	OT-ER
INSPECT:	1. Check oil level, add oil as required (A)	X					
	2. Drain moisture from tank by opening tank drain cock located in bottom of tank		X				
	3. Turn power off. Clean dust and foreign matter from cylinder head, motor, fan blade, air lines, inter-cooler and tank		X				
	4. Remove and clean intake air filters. Wash foam element in detergent solution. Do not oil				Y		
	5. Check V-Belt for tightness				Y		
	6. Change crankcase oil				X		
	7. Check entire system for air leakage around fittings, connections, and gaskets, using soap solution and brush						Quarterly
	8. Tighten nuts and cap screws as required						Quarterly
	9. Check and clean compressor valves, replace springs, discs, and seats when worn or damaged					X	
LUBRICATE:	1. Break-in period (first 40 hrs.) use non-detergent SAE 10W (type M1) motor oil. After Break-In:						
	1. Drain crankcase						
	2. Fill crankcase with AW machine oil 150				X		
		D-DAILY	W-WEEKLY		M-MONTHLY		S-SEMI-ANNUALLY
						A-ANNUALLY	

UNIT NAME REPRESENTATIVE DEPUTY UNIT NO. 91

UNIT NAME Descent Divers UNIT NO. 92

Exhibit 4
PREVENTIVE MAINTENANCE SCHEDULE

UNIT NAME _____ OPERATOR _____ UNIT NO. _____

		FREQUENCY					
		D	W	M	S	A	OTHER
INSPECT	1. Check all valves	y					
	2. Clean and inspect inside of generators. Wash with soap and water. Clean all dielectrics with glass cleaner				y		
	3. Test cooling water for nitrite content. Maintain between 500-1000 ppm. If not add water treatment chemicals		y				
	4. Blow down generators to remove deposits			y			
	5. Perform KI wet test and calibrate alarm monitor		y				
	6. Check all alarms					x	

D-DAILY W-WEEKLY M-MONTHLY S-SEMIANNUALLY A-ANNUALLY

[illegible]

UNIT NO. _____

FREQUENCY

[illegible]

1000

$$X \rightarrow Y$$

W. S. D. T. Y.

S-S-E-ANNUALLY

• **2007**

Table 10

Major Equipment Costs for Ozone
Disinfection System (July 1980 Replacement Costs)
Frankfort Wastewater Treatment Plant

	Unit Cost	Total Cost
Transformers, 3 each	\$ 54,000	\$162,000
Refrigerant Dryers, 2 each	36,000	72,000
Desiccant Dryers, 2 each	48,000	96,000
Centrifugal Compressors, 4 each	24,000	96,000
Ozone Generators and Dielectric Tubes, 4 each	114,000	456,000
Control System, 1 each	42,000	42,000
Heat Exchanger (Economizer), 1 each	5,000	5,000
Ozone Destruct Unit, Samplers, Monitors, and Flow Meters	60,000	60,000
TOTAL		\$989,000

Table 11

Ozone System Operating Costs
Frankfort Wastewater Treatment Plant

O₃ Generation Rate = 85 kg/d at 5.5 mg/L
FCI = \$500,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power	22.32	4.0	89
Operating Labor (.159 MY) (including repair and labor supervision)			101
Repair Materials (1% FCI)*			15
Supplies (10% O.L.)*			<u>10</u>
Total Operating Cost			215
<u>Overhead Cost</u>			
Insurance (1% FCI)*			15
Amortization (7% FCI)*			<u>152</u>
Total Overhead Cost			167
TOTAL OZONE COST ¢/kg (¢/lb)			382 (173)

MY, Man Year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

SOUTHWEST WASTEWATER TREATMENT PLANT SPRINGFIELD, MISSOURI

GENERAL

Springfield is located in the southwestern section of Missouri, approximately 212 miles southwest of St. Louis, Missouri (see Figure 15). The Southwest Wastewater Treatment Plant was upgraded (including installation of ozonation) in 1978. The plant (40 mgd design flow) currently treats approximately 30 mgd. The plant's treatment scheme incorporates raw sewage pumping, bar screening, comminuting, wastewater equalization, aerated grit removal, preaeration, primary clarification, pure oxygen activated sludge, secondary clarification, nitrification, final clarification, tertiary sand filtration, and ozone disinfection. The ozone system is currently on-line, although only 4 of its 13 ozone generators are being used. Design flexibility also allows for ozone disinfection of raw wastewater which is bypassed around the plant during wet weather periods. The plant's sludge handling system employs sludge thickening, aerobic sludge digestion, vacuum filtration, and ultimate disposal via land application. A plant flow diagram is shown in Figure 16. The plant was visited on 12 May 1982.

OZONE SYSTEM DESCRIPTION

The ozone system consists of 13 Union Carbide ozone generators, each rated at 265 ppd, and three covered ozone contactors. High purity oxygen from the cryogenic oxygen generating plant is fed to the Lowther Plate generators located on the second floor of the Process Building. The ozone generators convert the oxygen stream to a 3 percent (by weight) ozone stream by passing the pure oxygen between two electrodes across which flows an alternating high-voltage current (see Figure 17).

There are three ozone contact basins, each containing three stages, which are operated in a parallel mode. A schematic representation of a single ozone contact basin is shown in Figure 18. The stages within each ozone contact basin are mixing chambers where the wastewater and ozone gas are completely mixed by surface aerators. Each contactor is 102 ft long, 34 ft wide, and has an average liquid depth of 8 ft, providing a volume of 207,500 gallons. The total volume of the three contact basins is 622,500 gallons which provides a contact time of approximately 20 minutes at design flow. The contactors have been designed to dissolve 86 percent of the 3,400 lbs per day of ozone that can be produced by the Lowther plate ozone generators.

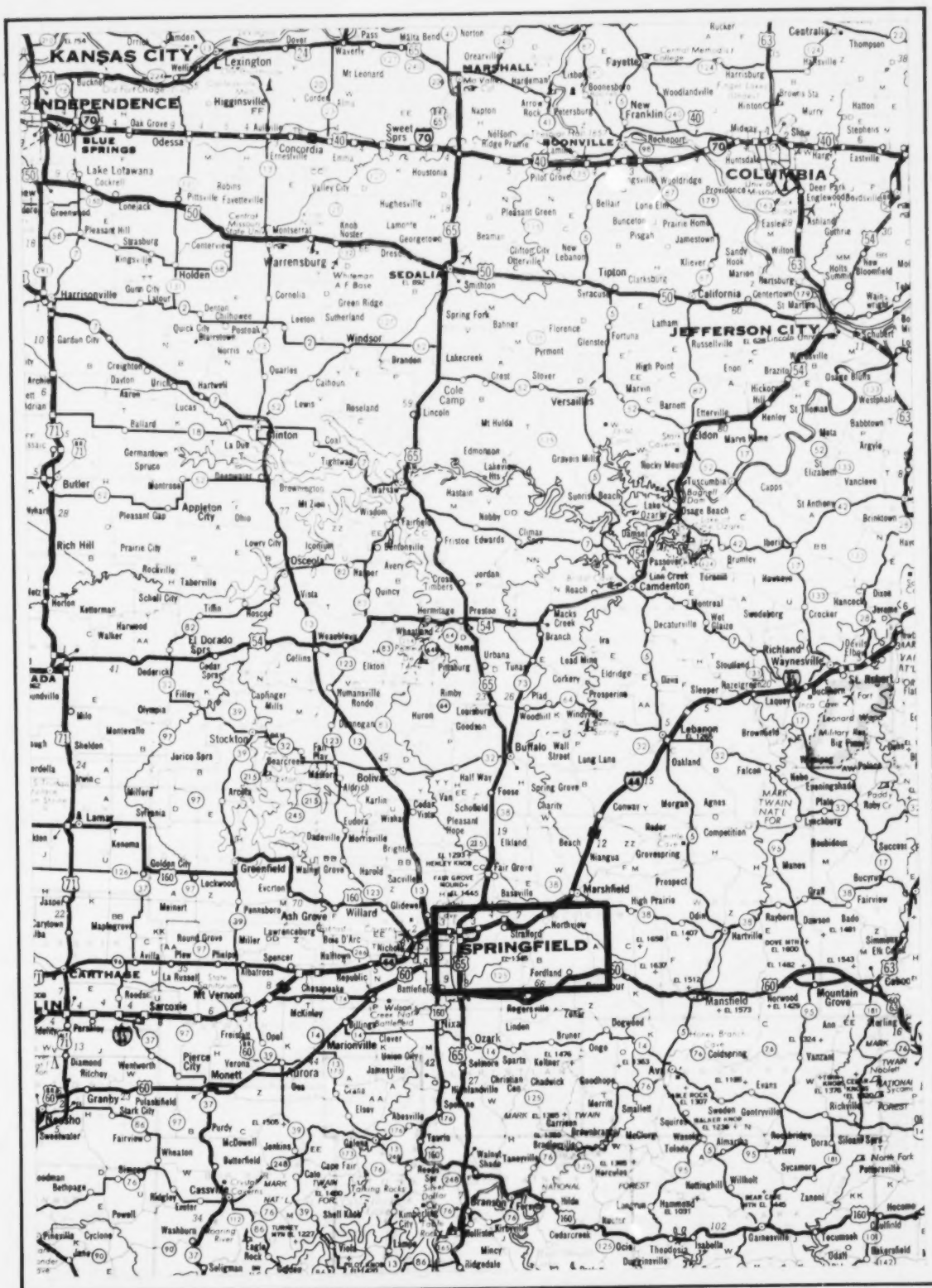


FIGURE 15 PLANT LOCATION MAP

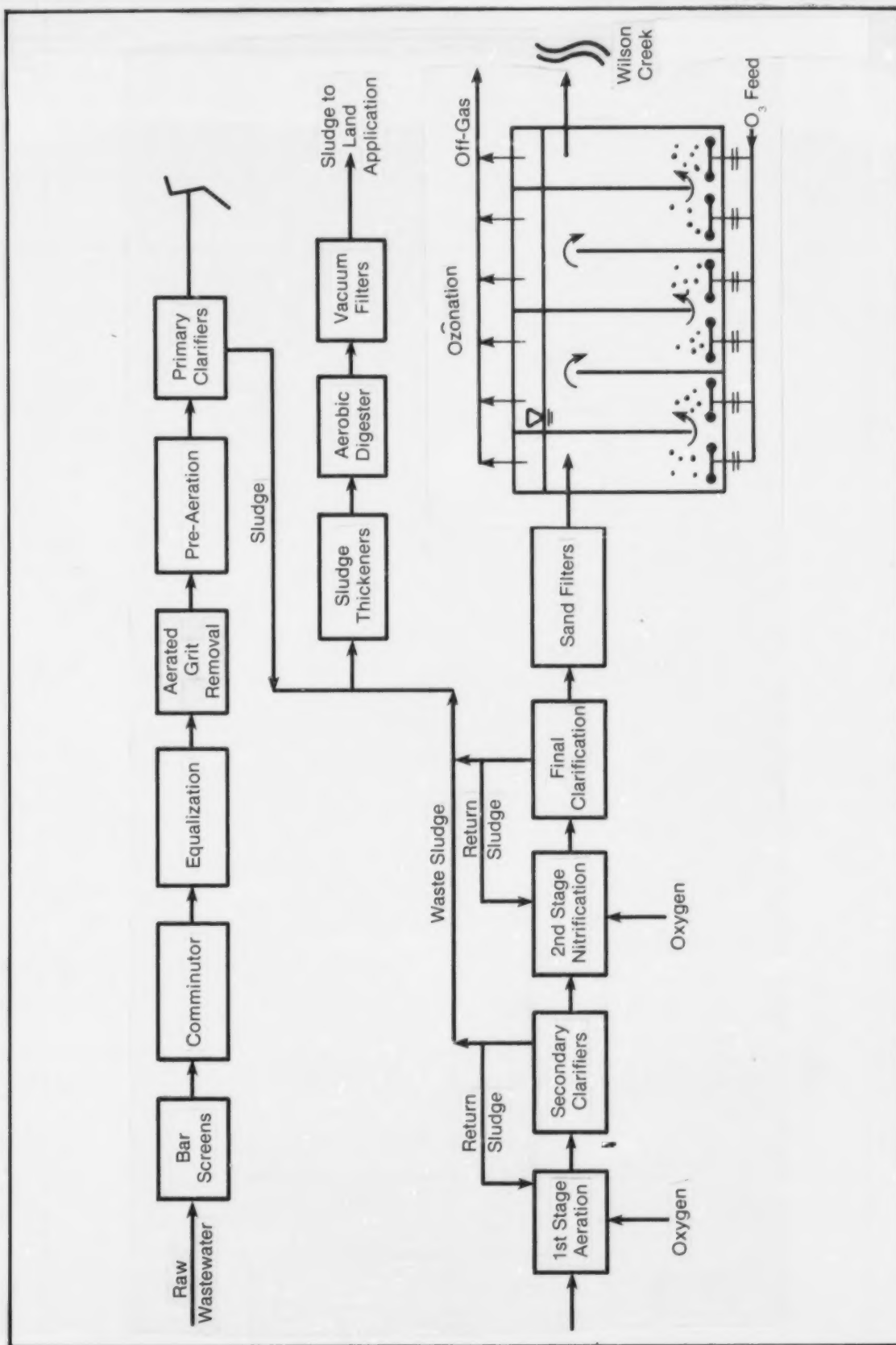
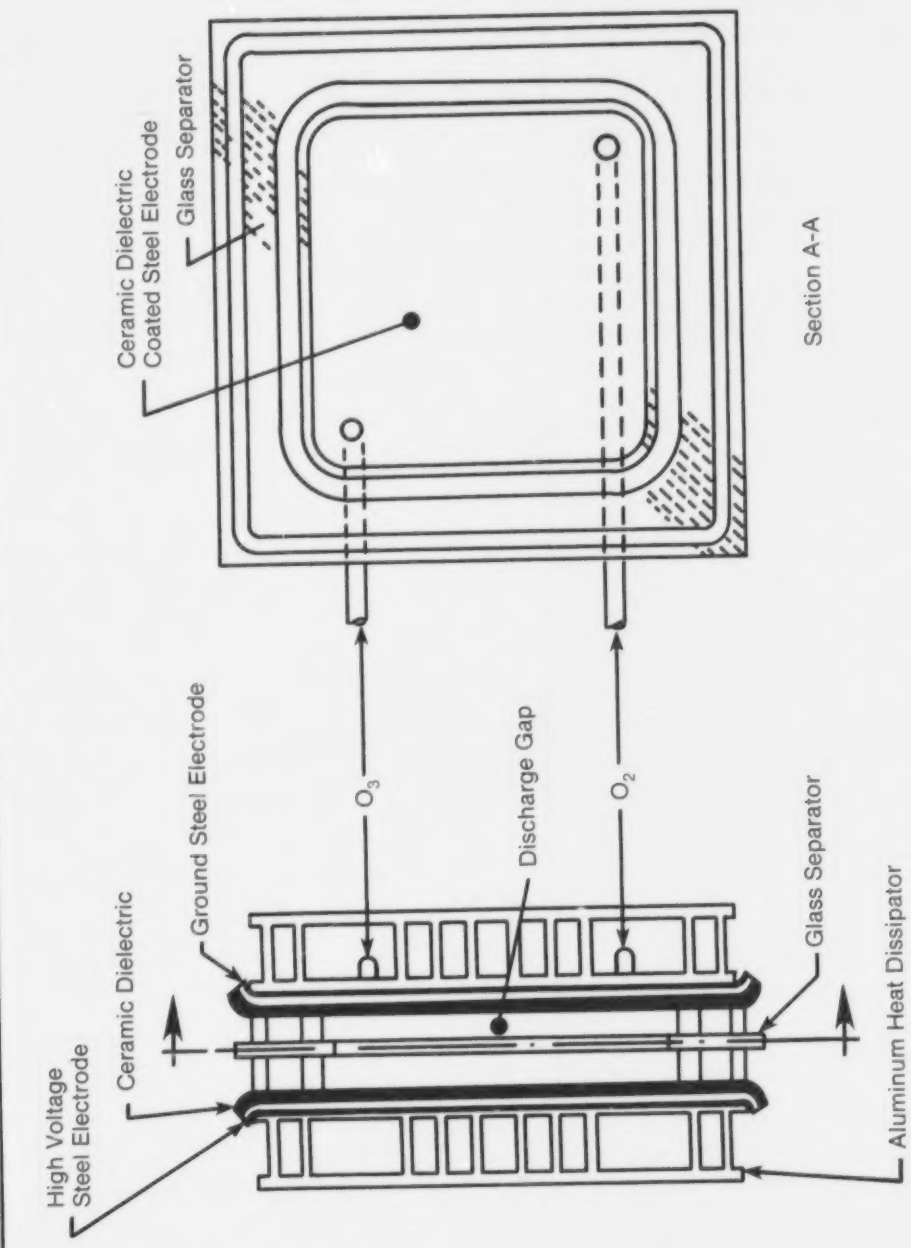


FIGURE 16 PLANT FLOW DIAGRAM



Section A-A

FIGURE 17 LOWTHER PLATE GENERATOR UNIT

2 1/4 W

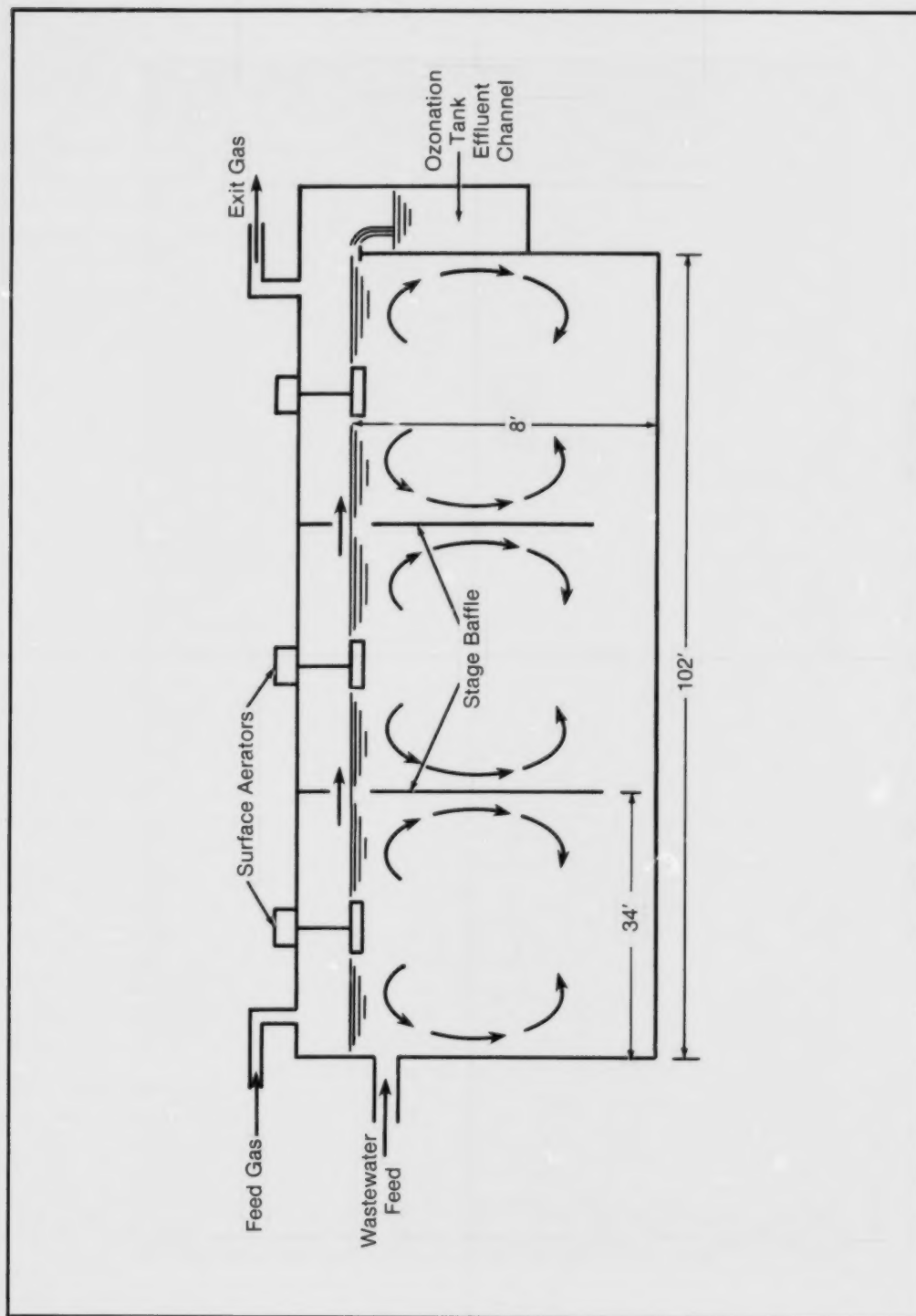


FIGURE 18 SCHEMATIC DIAGRAM OF OZONATION TANK

Filtered effluent passes by gravity through a 60 in. concrete pipe to the ozonation chamber influent channel. The flow of filtered effluent into each contactor is controlled by manually-operated sluice gates at the influent end of each tank. The liquid level in the contactors is maintained by a weir at the outlet end of each contactor.

Ozone/oxygen gas from the ozone generators is applied to the first stage of each contactor. The wastewater and ozone gas pass co-currently through the second and third stages of the contactor. The unused portion of gas in the contactor is drawn from the third stage by the pure oxygen system gas feed blowers. The blowers discharge gases drawn from the contactors into the high-purity oxygen gas feed line to the pure oxygen-activated sludge system. Under normal operating conditions, one gas feed blower is in operation while the second blower is used as a standby unit.

A pressure controller down stream from the ozone generators maintains the generator feed gas pressure at approximately 12 psig. The pressure within the ozone contactors is maintained at a slightly negative pressure (0 to -4 in. of water). Contactor pressure is maintained by controlling the activated-sludge oxygen feed blower which draws gas from the third stage of the contactor. If contactor pressure decreases, a bypass valve around the blower opens to allow a pressure increase. Conversely, the bypass valve closes if the contactor pressure increases.

The ozonation system has been provided with various safety features to protect the operator. Ozone is a toxic gas, pale blue in color, and has a distinctive pungent odor recognizable at concentrations well under one ppm by volume. Ozone gas-detecting equipment has been provided in the ozone generator room and on the contactor deck. If ozone is detected in the ozone generator room, the flow of oxygen to the ozone generator is shut down. If an ozone leak is detected around the contactors, the flow of oxygen to the ozone generators is shut off, the ozone generators shut down, the surface aerators shut down, and the flow of oxygen from the contactors to the oxygenation system shut down. However, the combustible gas detection systems and purge blowers remain operational.

Gas samples are continuously drawn from the first and last stages of the three contactors by sample pumps located on the contactors. Sample flow is controlled by solenoid valves located at the pump suction, allowing sequencing of samples from the first and last stages of each contactor. A sample sequencing

programmer is included with the system to control the position of the solenoid valves. A timer is used to rotate the programmer to the next sequence by energizing and de-energizing the proper solenoid valves.

Each analyzer is provided with two switches, one which trips at the detection of a 25 percent Lower Explosive Limit (LEL) in the sample stream, and the other which trips at 50 percent LEL in the stream sample. When a 25 percent LEL condition is reached, an alarm sounds both at the local panel and on the main control panel. The sequencing program stops so that the same sample continues to be monitored, the gas feed blower shuts down to essentially isolate the ozone contactors from the oxygenation reactors, and the air purge blowers on top of the reactors start up to purge the gas space. Also, when a 25 percent LEL is detected in the oxygen supply, the ozone generators shut down.

If the combustible gas level continues to increase, a second alarm will sound at 50 percent LEL and the mixers in the affected system will shut-down.

Composite samples are drawn automatically from the ozonation tank effluent channel. The sample is pumped to a sampler located on the ground floor of the main equipment building. The frequency of sampling by the sampler is controlled by a signal from the plant influent flow meter.

FACILITY OPERATIONS

Ozonation System Control

Oxygen normally flows to the ozone generators, then to the ozone contactors, and finally to the pure oxygen-activated sludge basins. Bypass oxygen flow directly to the pure oxygen activated sludge basins occurs only as make-up flow when the vent oxygen from the ozone contactors is insufficient to supply the reactor demand as directed by the pressure control system.

Oxygen flow to the ozone generators is maintained proportional to the contactor effluent flow rate. A low-limit relay receives a minimum oxygen flow signal to prevent blow-off from the oxygen generation facility; this is set at 8.75 psig to maintain a minimum oxygen flow of 36,000 scfh (this will also allow the required flow to the gas feed blowers down stream of the ozone contactors to keep recycle flows from overheating the blower discharge and causing a blower shut-down). High limit relays limit the maximum oxygen flow to the ozone generators; this is

set at 12.07 psig to limit peak ozone generator flows to 56,700 scfh.

A flow controller compares the generator set point with the pressure- and temperature-compensated flow signal and sends an output signal to a flow control valve to adjust the valve position and obtain the required flow. The controller is set for reverse action; thus, increasing oxygen flow causes a decreasing controller output, which causes a valve to close back and maintain the flow of oxygen to the ozone generators.

The actual method for controlling ozone dose and the associated level of ozone disinfection is by bringing up additional generators. Under normal operation, oxygen always flows through all 13 ozone generators to prevent the accumulation of moisture. During the plant visit, only four ozone generators were required to produce sufficient ozone concentrations for proper disinfection. For example, if inadequate disinfection occurred, then a fifth or possibly a sixth ozone generator would be put on-line, thus effectively increasing the ozone concentration going to the contactor basin.

Start-up and Operational Problems

At the time of the plant visit, the Lowther plate units were approximately five years old and were being replaced by new Union Carbide/Lotepro units. The old units were being replaced when the ozone production in that particular unit dropped off significantly. Units were being replaced rather than re-built because the new units only cost \$200 more than the re-built ones. It should be noted that there are three 30-cell banks per generator. The new model's 30-cell banks are approximately 10 to 11 in. shorter and are constructed with better gasket material. The approximate cost at the time of the plant visit was \$4,600 per bank.

Plant personnel indicated that the primary operational problem encountered with the ozone system was generator maintenance. Generator maintenance includes replacing fuses, SCR's, snubber boards, cleaning cell modules, and calibrating ozone monitors. The outer surfaces of the generation cells must also be periodically cleaned due to dust accumulation. Frequently, when using rags to clean the cell modules, the silicone gaskets become displaced and cause ozone leakage. When ozone leakage in a cell is noticed, the cell is simply capped off by bypassing the oxygen

and ozone manifold tubes to that particular cell. It is estimated by the plant's electrical engineer that every type of component in the ozone generating system has been replaced in the last three years due to failure.

An additional problem is that the company which manufactures the capacitors for the ozonators' DC power supply no longer makes the same physical size. In the future, when the capacitors are replaced, the plant engineer will have to extensively re-work the connections and fittings in the generators. Many of the capacitors will likely have to be replaced in the next year.

Fan belts which drive the exhaust fans in the ozone generation room frequently fail and must be replaced. It is estimated by the plant's electrical engineer that the fan belt replacement frequency is approximately four belts per generator per year.

Ozone generator side panel fasteners frequently fail and must be replaced when O&M personnel are required to work inside the ozone generators. The ozonators were originally supplied with twist-and-lock type fasteners, but these have been gradually replaced by more sturdy screw-type fasteners.

The operator also indicated that the ozone gas sampling systems have poorly designed pumps, valves, connections, and incompatible materials of construction. The ozone samplers inside the ozone generator room, which monitors percent ozone by weight, leaks almost constantly. This continual and dangerous ozone leakage has essentially precluded the use of these samplers during normal operation. The major occurrences of leakage have been associated with bad O-rings in the solenoid valves and pump diaphragm deterioration. When sample pump diaphragms are replaced, they seem to last approximately four days before they deteriorate. Ozone sample pump diaphragms used to sample contactor off-gases typically last one month before deterioration. The plant's solution to ozone sampling equipment leakage is simply not to use the equipment.

Ozone leakage from the ozone generators appears to be a continual problem. When ozone leakage from a particular cell is detected, that cell is bypassed from both the inlet and outlet manifolds, thus eliminating the leakage. It is estimated that in the five-year-old cells approximately two to three cells per month fail due to ozone leakage. Ozone leakage from a particular cell has been known to cause electrical discharge from the cell to the frame of the ozone generator, thus blowing the cell's fuse.

In the past year, cell failures have averaged approximately 4.5 cells per month in the five-year-old units. Of these cell failures, approximately half have been attributed to leakage, and the remaining half attributed to shorting out as indicated by continual blowing of fuses. The 4.5 cell per month failure rate represents having to replace approximately seven 30-cell banks in 10 months due to low production rates. The new generating cell units which have been purchased in the last year are experiencing approximately one cell failure per month.

The Dasibi ozone concentration analyzers used at the plant require cleaning of the plug-in circuit board terminals approximately two times per year. Calibration of the UV source output is quite difficult and time consuming and is required approximately once every three months. UV bulbs need replacing approximately once a year; additionally, the ozone analyzers, which are mounted above the ozone contactor, require cleaning of the quartz transmission windows once a month.

Operations and Maintenance Staff

Operator motivation and interest in the ozone disinfection system appeared to be good during the plant visit. Operation of the ozone system appears to be a joint effort between the plant chemist and the plant electrical engineer. The plant's laboratory facilities seem to be adequate to monitor and control the disinfection system. At the time of the plant visit, laboratory personnel were unfamiliar with the potassium iodide wet test method; however, they seemed more than willing to learn the procedure and plan to use it in the future to measure both contactor efficiency and generator output. The plant's electrical engineer has a more than adequate understanding of the ozone generator process and related equipment.

Ozone generator performance testing was conducted during the site visit. During these tests, ozone gas concentration entering and leaving the contactor chamber was measured by the potassium iodide wet test method. Additionally, ozone generator production, gas flow rates, and power consumption rates were measured. The results of the ozone generation system testing are presented in Table 12. It should be noted that the results of the contactor transfer efficiency test were 95 percent as compared to a design transfer efficiency of 90 percent.

MAINTENANCE

The major portion of the routine maintenance schedule consists of inspecting and cleaning the ozone generation cells. The required maintenance consists of bypassing leaking or damaged cells, replacing SCR and cell fuses, replacing cooling-fan belts, and repairing ozone gas-sampling equipment. It is estimated that approximately 520 hours per year of repair labor is required for these tasks. In 1981 the plant spent in excess of \$50,000 in replacement parts. In summary, the most time-consuming maintenance requirement is repairing ozone leaks, whether it be in generation cells, or sampling and monitoring equipment.

OPERATIONS AND MAINTENANCE COST

Operations and maintenance costs could not be calculated because the fixed capital investment for the ozone system could not be separated from the pure oxygen system.

Table 12

Ozone Generation Testing and Contactor Transfer Efficiencies
Southwest Wastewater Treatment Plant
Springfield, Missouri

Parameter	Value
Carrier Gas Flow Rate (Q_g)	26,160 std. liters/min.
Plant Effluent Flow Rate (Q_L)	78,850 liters/min.
Ozone Conc. in Contactor Inlet Gas (Y_1)	13.2 mg/L
Ozone Conc. in Contactor Outlet Gas (Y_2)	0.69 mg/L
Applied Dose	4.4 mg/L
Ozone Transferred	4.2 mg/L
Contactor Transfer Efficiency	95%
Ozone Generator Power Consumption	151 kw*
Ozone Generation Rate	1,060 lb/day (479 kg/day)
Ozone Production Electrical Energy Requirement	3.42 kwh/lb produced

Definition of Terms:

Applied Ozone = $Y_1 (Q_g/Q_L)$

Ozone Transferred = $(Y_1 - Y_2) (Q_g/Q_L)$

Contactor Transfer Efficiency = $(Y_1 - Y_2) Y_1 \times 100$

*Total power consumption of the four generators that were operating during the test, including cooling-fan power consumption.

BROOKINGS WASTEWATER TREATMENT PLANT
BROOKINGS, SOUTH DAKOTA

GENERAL

Brookings is located approximately 60 miles north of Sioux Falls, South Dakota on Interstate 29 (see Figure 19). Construction of the plant was completed in October 1980 at a cost of 9.35 million dollars. The plant was visited on 3 May 1982.

The Brookings plant (3.0 mgd design flow) currently treats an average flow of 2.2 mgd. The plant's treatment scheme incorporates raw sewage pumping, grit removal, primary clarification, rotating biological discs, activated sludge, secondary clarification, filtration, and ozone disinfection with chlorine backup. The ozone system is currently down because plant personnel feel that chlorine is significantly less expensive. The plant's sludge handling system employs anaerobic digestion, gravity thickening, and subsurface land application of liquid sludge. A plant flow diagram is shown in Figure 20.

The plant's final effluent discharges into the Big Sioux River, which is water quality limited. Uses of the Big Sioux River include domestic water supply, warm water semi-permanent fish propagation, limited contact recreation, wildlife propagation, livestock watering, and irrigation. The plant's NPDES permit limits are presented in Table 13.

OZONE SYSTEM DESCRIPTION

The Brookings plant was designed to use ozone for the disinfection of filtered effluent. It should be noted that the ozone system is currently not on-line and chlorine gas is being used. The ozone system is designed to produce 250 lb per day at a power consumption rate of less than 12 kwh per lb of ozone produced. Ozone is produced from compressed air in two Emery horizontal tube generators, each rated at 125 ppd. A schematic representation of the Brookings ozone disinfection system is shown in Figure 21.

Two Ingersoll-Rand Class ESV-1P-NL air preparation units, which are completely self-contained non-lubricated compressed air power plants, are used. Each unit is furnished with a base of welded steel on which the compressor, motor, aftercoolers, inlet filter, separator, control cabinet, and receiver are mounted.

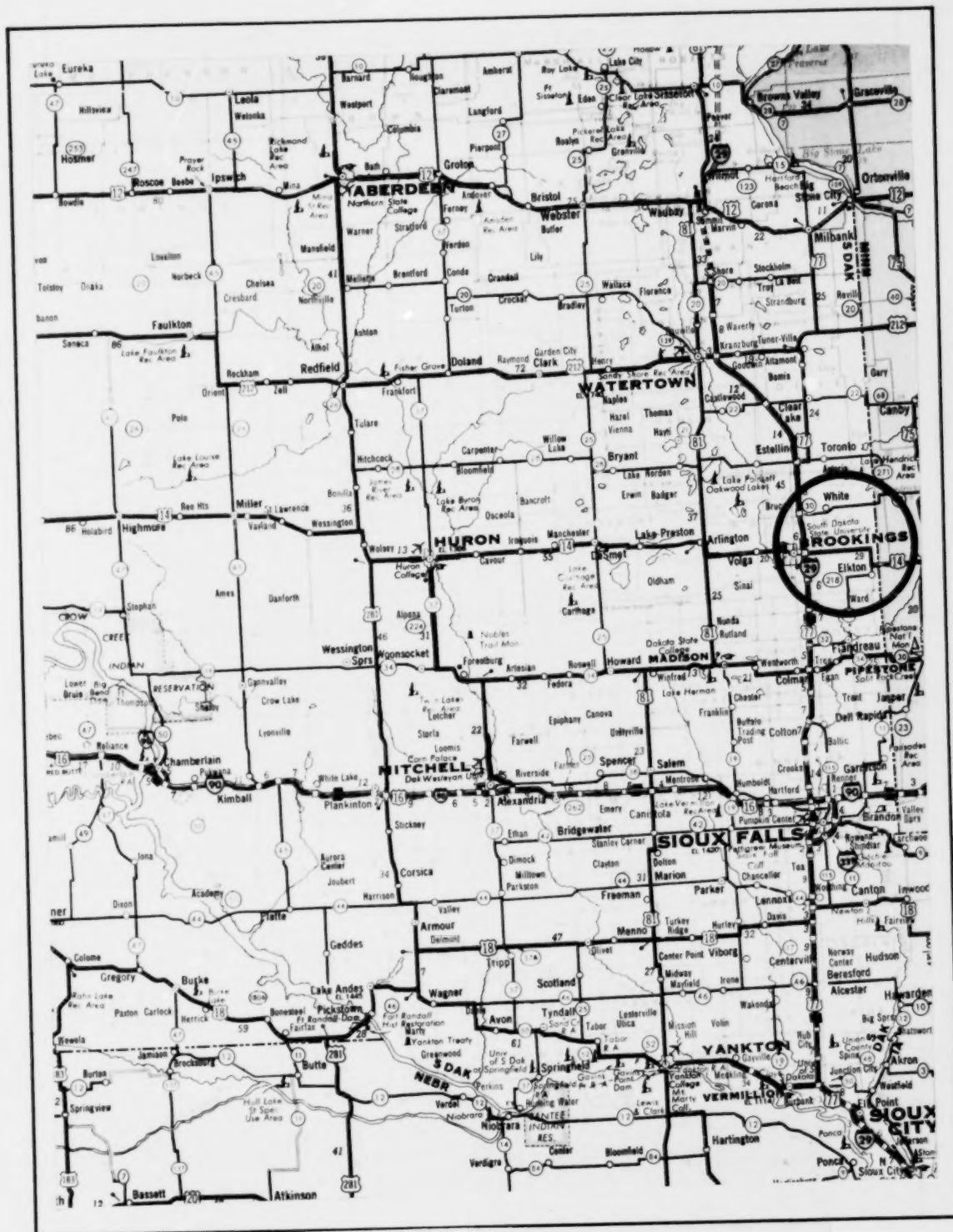


FIGURE 19 PLANT LOCATION MAP

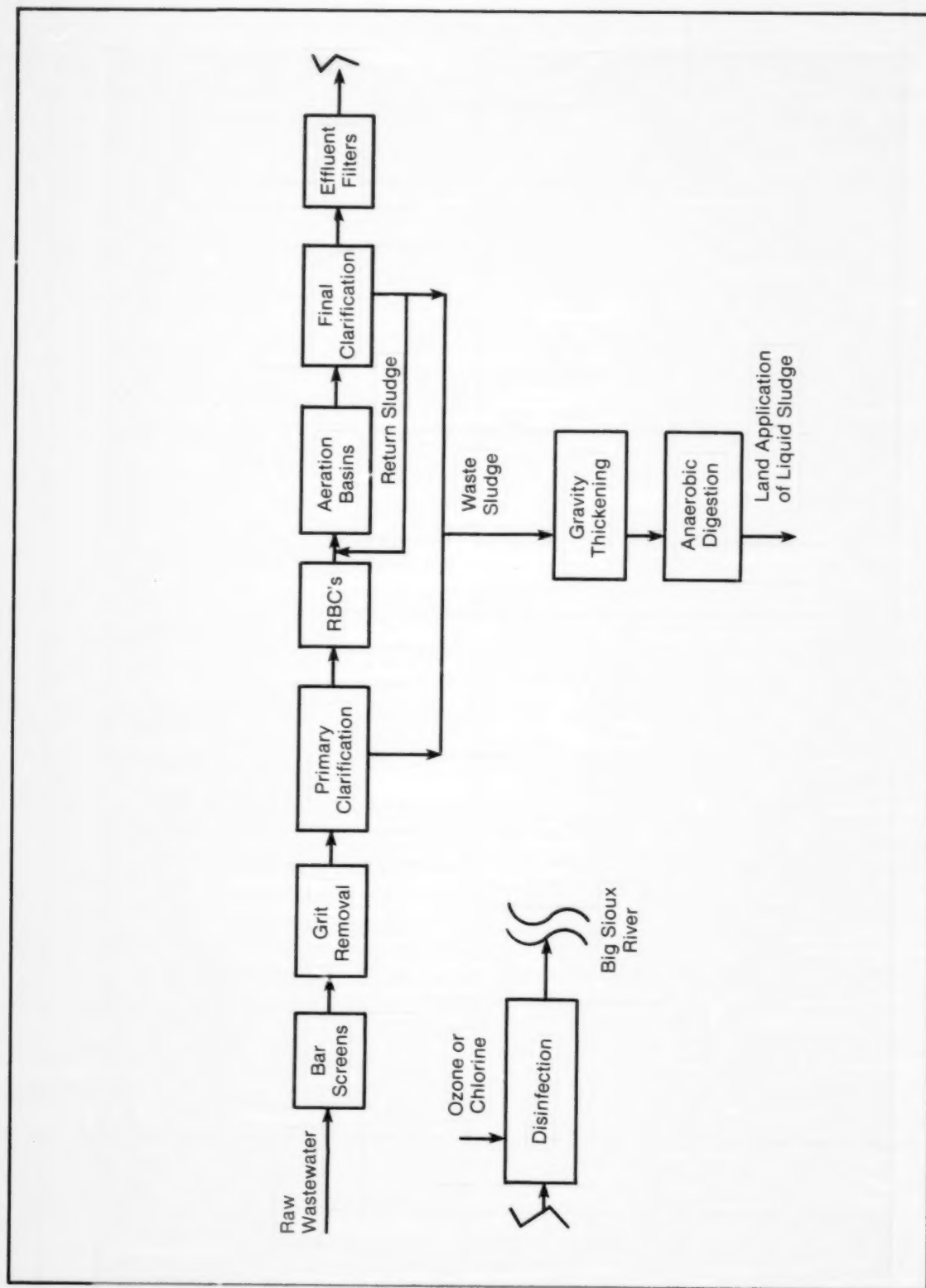


FIGURE 20 PLANT FLOW DIAGRAM

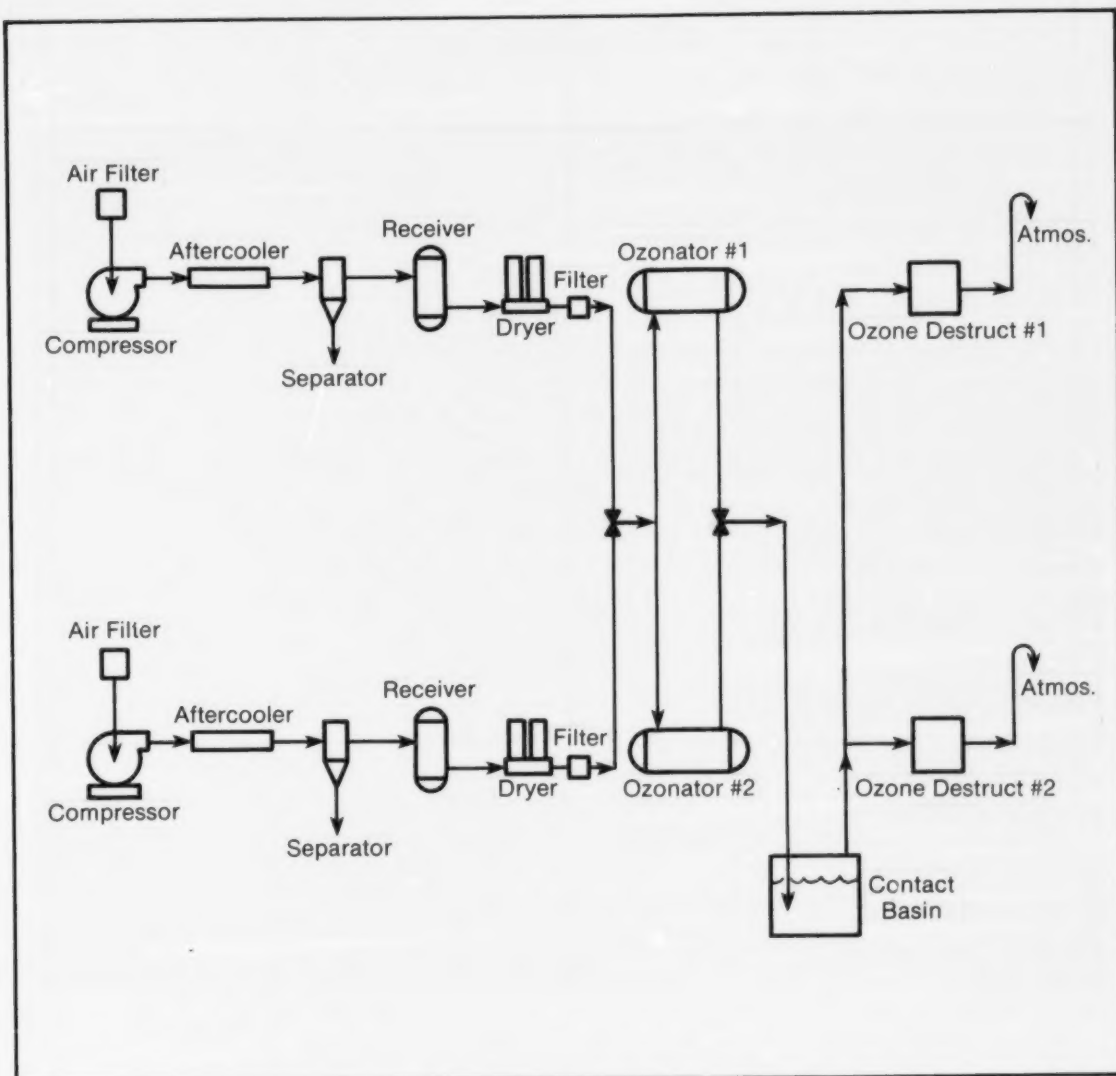


FIGURE 21 OZONE DISINFECTION SYSTEM

Table 13

Brookings, South Dakota Wastewater Treatment Plant
NPDES Discharge Limitations

Parameter	Discharge Limitations	
	Monthly Average	Weekly Average
BOD ₅ , mg/L	N.A.	20
Suspended Solids, mg/L	30	45
Ammonia-Nitrogen, mg/L	N.A.	6.0 (Nov-Mar) 2.0 (Apr-Jun) 1.0 (Jul-Sep) 8.0 (Oct)
Fecal Coliform, #/100 ml	N.A.	3,000 (Apr-Jun) 1,500 (Jul-Sep) N.A. (Oct-Mar)
Oil and Grease	Shall not exceed 10 mg/L	
Dissolved Oxygen	Shall be greater than 7 mg/L (Jul-Sep)	
	Shall be greater than 9 mg/L (Oct-Jun)	
pH, std. units	Shall remain between 6.0 and 9.0	

The compressor is driven with a 30-hp, 460-v, 30- and/or 60-cycle current and will provide 140 cfm of oil-free air at an 80 psig discharge pressure.

Two Deltech Heatless Duplex Driers (Model GS) are utilized to provide dry air at dew points as low as -60°F. Each unit provides a continuous supply of dry air by automatically cycling the operation of two desiccant beds. While one bed is absorbing moisture from the inlet air, the other bed is regenerated using a portion of the dried air. The drier includes two desiccant chambers, a pressure regulated purge air system, exhaust purge air muffler, and dew point indication by a visible strip which changes color in response to the moisture content.

The two Emery Model 9263 ozone generators are constructed of stainless steel to safely maintain an internal pressure of 15 psig. All parts of the ozonator which are in contact with ozone are constructed of stainless steel, glass, or other ozone-resistant materials. A cross sectional view of the ozone generator is shown in Figure 22. Cooling water is required to cool the ozone generator. The inner high-tension electrode consists of a metal screen which is physically secured to the inner surface of the glass dielectric. Each inner electrode/dielectric is positioned inside a grounded metal tube which acts as the other electrode. Illustrations of the dielectric tubes are shown in Figure 23. Electrical power for the ozone generator is obtained from a transformer/reactor. A voltage controller is installed on the primary side of the high-voltage transformer to enable variation of ozone production between 10 and 100 percent of capacity.

A gas diffusion system suitable for effluent aeration and ozone diffusion is provided in two parallel disinfection basins. Each basin has a volume of 58,600 gallons, which provides a contact time of 30 minutes at the design flow rate of 3.0 mgd.

The ozone system includes two ozone destruct units which incorporate a catalyst and a heating device to provide energy to the ozone-laden gas to induce molecular reduction of the ozone concentration. The temperature of the destruct unit is maintained at approximately 270°F. A schematic representation of a destruct unit is shown in Figure 24.

The ozone generator cooling-water unit is a closed-loop cooling system. Major equipment includes two pumps, a holding tank, a duplex strainer, and a plate heat exchanger. Cooling water from the holding tank is pumped through the plate heat exchanger where it is cooled. It then travels through the ozone generation skid system and returns to the holding tank. Heat is extracted from the water at the plate heat exchanger by utilizing effluent from the aeration/ozonation contactor.

FACILITY OPERATIONS

Ozone System Control

Room air is pulled into the air compressor through intake filters, compressed, cooled by a water-cooled aftercooler, and stored at 80 psig in an ASME-rated receiver. The 80 psig air is then directed through a temperature gauge, a pressure gauge, and into a desiccant air dryer where the compressed air is dried to

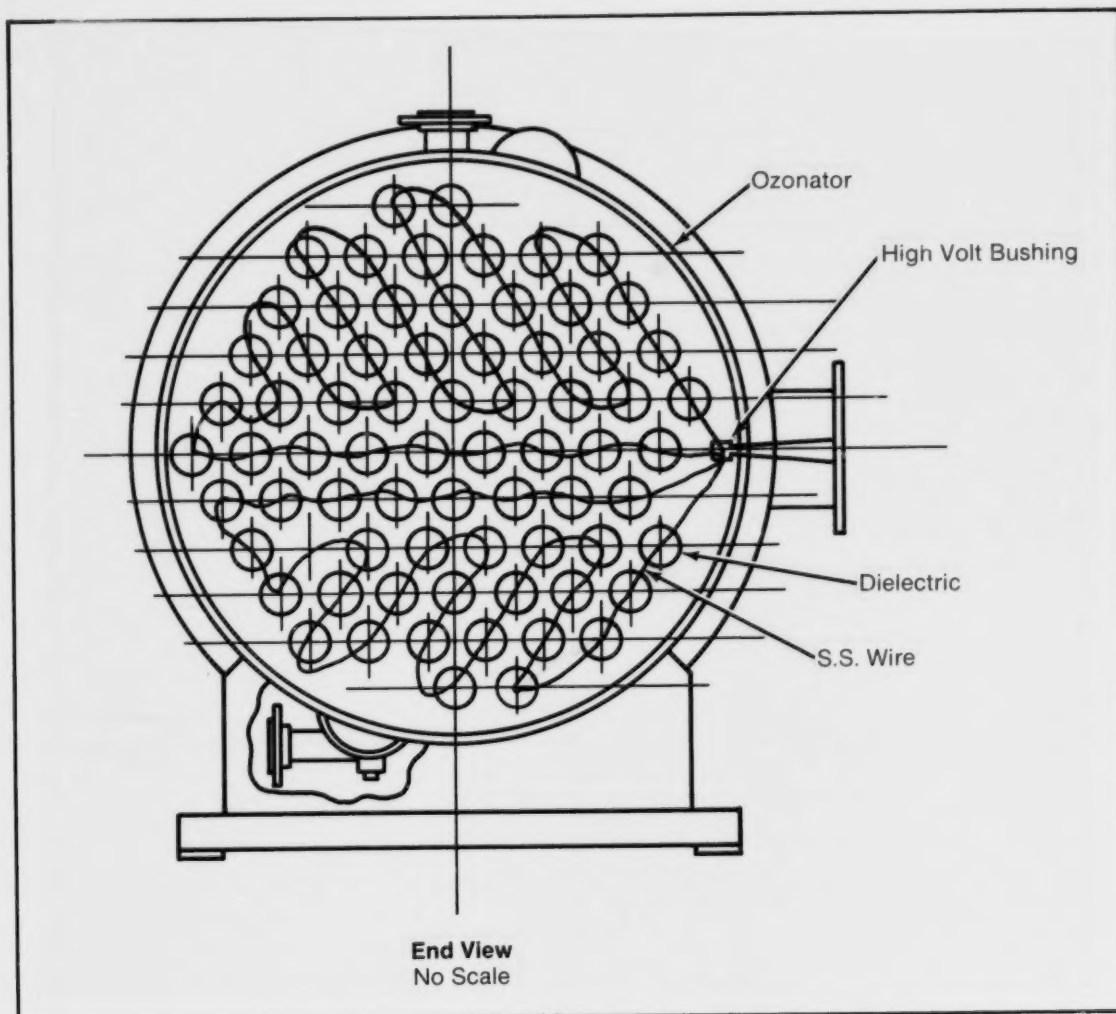


FIGURE 22 CROSS SECTIONAL VIEW OF OZONATOR

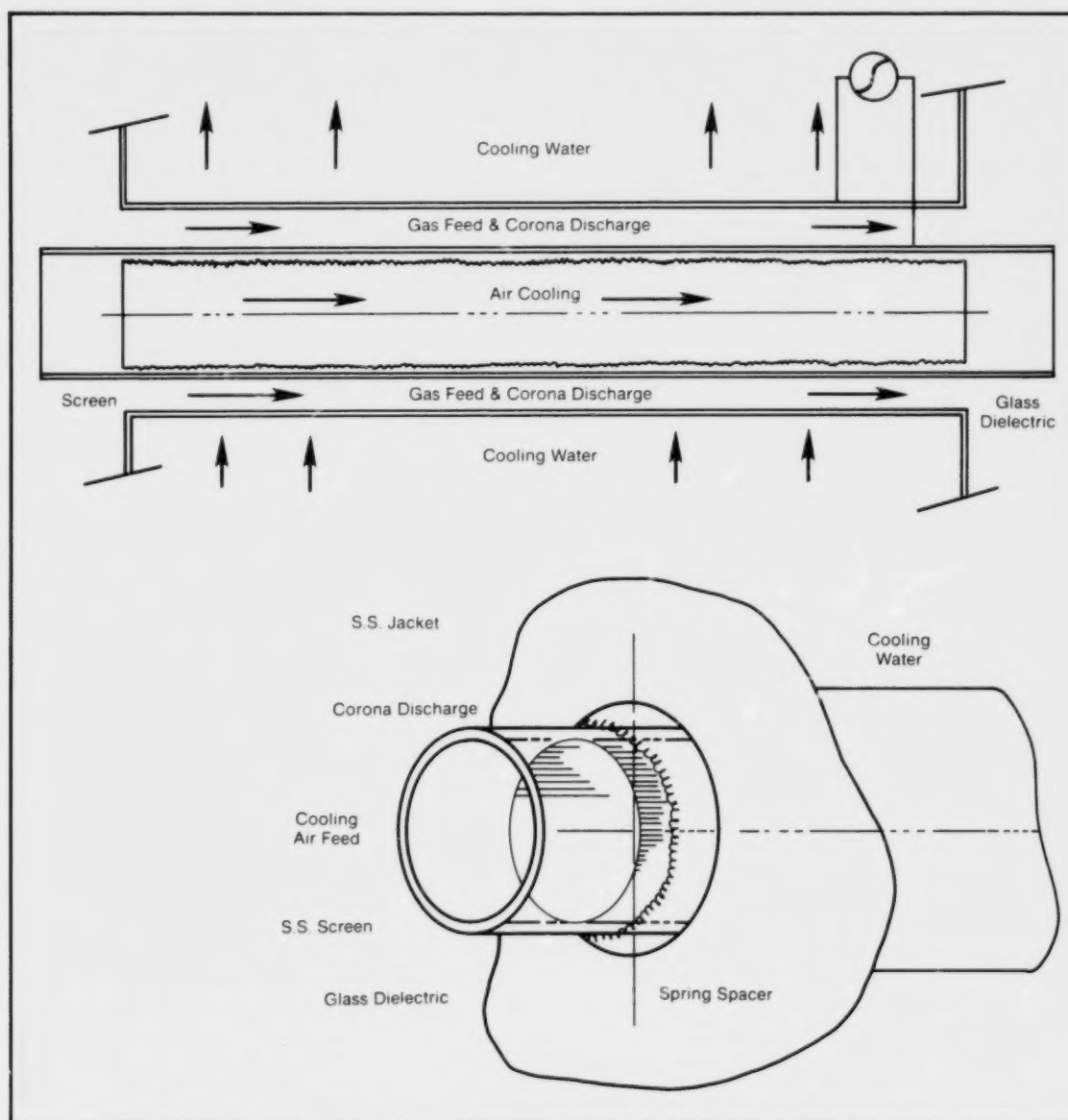


FIGURE 23 BREAKAWAY VIEW OF DIELECTRIC TUBES

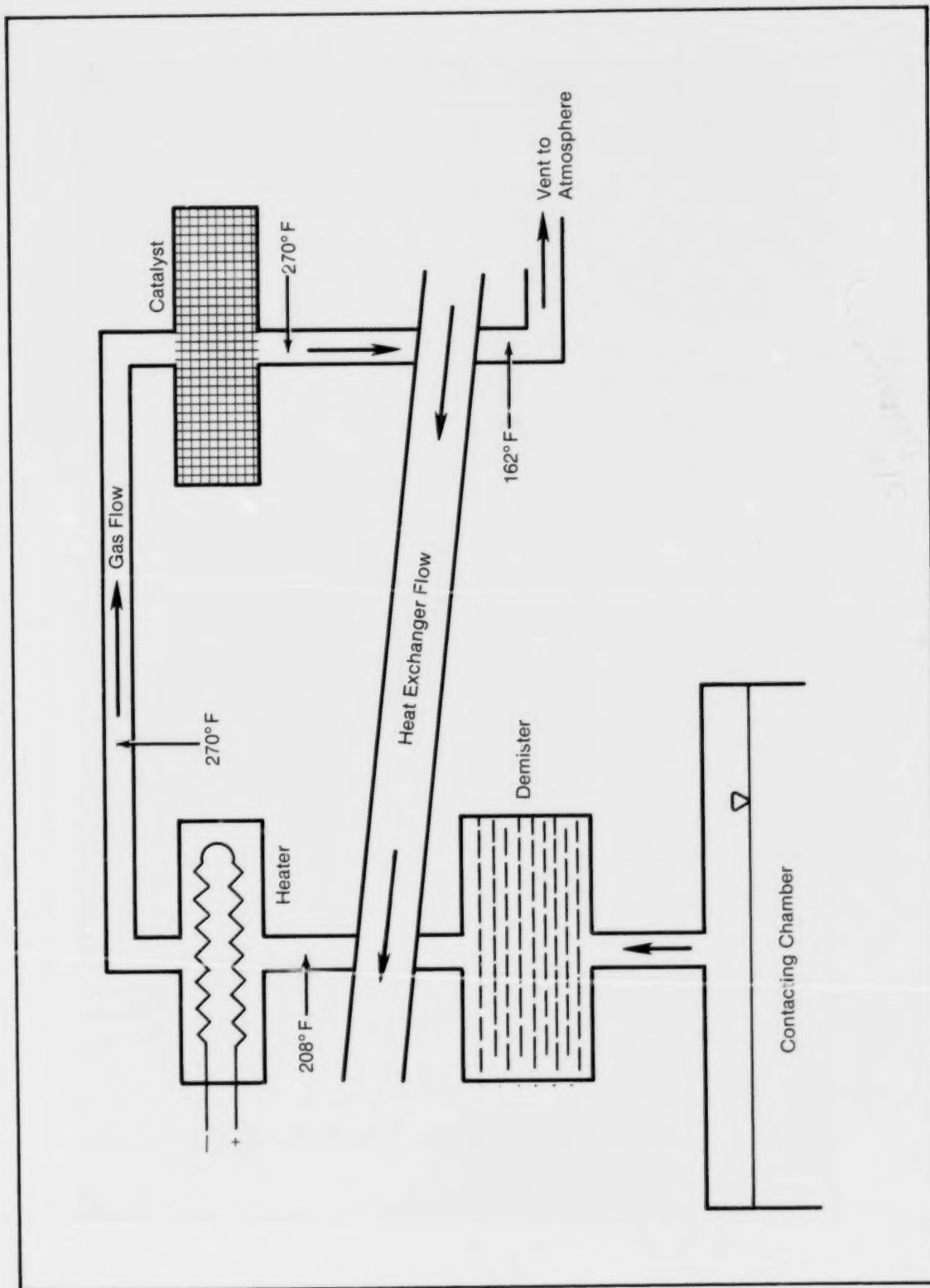


FIGURE 24 OZONE DESTRUCT UNIT

a dew point of -60°F . After passing through a filter (to remove any residual desiccant particles) and a rotameter flow controller, the air pressure is reduced via a pressure-reducing valve to 15 psig. The air then passes through another pressure gauge and a temperature gauge before entering the ozonator. From the ozonator the ozone-enriched air is piped through another temperature gauge and pressure gauge, and then is split into two trains for dissolution into the two contactor tanks. Inside the contactor basin, the porous ceramic diffusers produce fine bubbles of ozone, which enhances ozone dissolution. The wastewater flow is circulated through both contactor cells before being discharged from the system. The contactor off-gas is passed through the ozone destruct system to destroy any residual ozone molecules before discharging the gas stream to the atmosphere.

The ozone generators will be shut down under the following conditions:

- Low or high gas pressure in the ozonators - Each ozonator has a high and low pressure switch; if the pressure is below 8 psig or above 15 psig, the ozonators will shut down.
- Low air feed flow - Each ozonator has a low flow switch in the air inlet; at low air flow the ozonators will shut down.
- Low cooling-water flow - Each ozonator has a low flow switch in the outlet of the cooling water from the ozonator; at low cooling-water flow the ozonators will shut down.
- High dew point of air feed to ozonators - Each desiccant dryer has a dew-point sensing element; at high dew point (i.e., -30°F) the ozonators will shut down.
- Dielectric failure - Each ozonator has a dielectric failure circuit; in the event a dielectric fails, the ozonator will shut down.
- Auxiliaries shutdown - In the event both compressors and desiccant dryers are off-line at the same time, the ozonators will shut down.

- High concentration of ozone in the generator room - The ozonators will shut down in the event the ambient ozone concentration in the generator room exceeds 0.1 ppm.
- High product gas temperature - The ozonators will shut down if the product gas temperature exceeds 130°F.

Ozonation system performance testing was conducted on 3 and 4 December 1980 by Emery Industries, Inc. of Cincinnati, Ohio. Tests conducted on the Dasibi ozone production monitor showed the Dasibi readings were 1.7 percent to 10.1 percent high and therefore the span setting of the monitor was changed. It should be noted that the KI Test Procedure has a combined error possibility of +/- 5 percent. Dasibi readings, according to the vendor manual have an error of +/- 3 percent and therefore the adjustment made was minor.

The results of the performance testing show that each ozone unit is capable of producing up to 166 lbs per day of ozone for a total system capacity of 332 lbs per day of ozone. Production at the rate of 332 lbs per day consumed only 10.2 kwh per lb of ozone. The compressors, dryers, cooling water system, and ozone generators were run continuously for more than 24 hours with no malfunctions. Power consumption results for each component of the ozone system are indicated in Table 14. Ozone generation and system efficiency results for eight power settings are shown in Table 15.

Contact transfer efficiency tests conducted with treated wastewater on 27 November 1981 by plant personnel indicate 67 percent ozone dissolution. Corresponding wastewater characterization was unavailable for this date. The cause of this low percent dissolution is unknown at this time.

Start-up and Operational Problems

The ozone system was only operated for approximately four months, from April to July 1981. After this time the system was shut down because the plant superintendent felt that chlorination/dechlorination was a significantly more cost-effective means of disinfection.

Ozone System Power Consumption
Brookings Wastewater Treatment Plant
3 and 4 December 1980

Note: Total power usage with all equipment operating = 51.20 kw.

Table 15

Ozone System Performance
Brookings Wastewater Treatment Plant
December 3-4, 1980

Ozonator Power kw	Ozone Production lbs/day	Ozonator Efficiency kwh/lb O ₃	Total System Power kw	System Efficiency kwh/lb O ₃
10	47.73	5.028	35.6	17.901
15	67.49	5.334	40.6	14.438
20	94.86	5.060	45.6	11.537**
25	107.31	5.591	50.6	11.317
30	128.37*	5.609	55.6	10.395**
35	137.27	6.119	60.6	10.595
40	153.76	6.243	65.6	10.239**
45	166.10	6.502	70.6	10.201**

*Point closest to rated system capacity of 125 lb O₃/day

1. Above "System Efficiencies" include power usage for all equipment associated with the production and destruction of ozone in the Emery system.
2. Above data is for Ozonator No 2 based on tests run on 4 December 1980. Ozonator No. 1 would be similar.

**These data points are with the transformer on the "C" Tap; all others are at the "D" Tap.

During the four months of operation, the system was down for approximately one week. The reasons for this down time are as follows:

- A kw meter failed and was reading zero kw. The meter was sent back to the manufacturer for repairs.
- An end glass in an ozonator housing cracked and was replaced by a new one sent by the manufacturer.
- A Dasibi percent ozone production analyzer failed and read zero. The problem was corrected by replacing a circuit board.
- A solenoid valve in the ozone gas sampling system froze and had to be replaced.
- Several ozone leaks were detected both in the generator room and the contactor deck. In the generator room the smell of ozone was always prevalent and an exhaust fan had to be turned on prior to entering the room. In addition, the ambient ozone alarms would sound if the ventilation system was turned off. More serious leakage was detected on the contactor decking. It was determined that ozone was deteriorating the seam-sealer material in the concrete seams. Rapid deterioration occurred even though this sealer was made of silicone.

Operations and Maintenance Staff

Operator motivation and interest in the ozone disinfection system appeared to be adequate during the plant visit. Due to the system's inoperability during the plant visit, it was difficult to assess the operators' understanding of the process. However, the plant's superintendent felt that his staff was adequately trained to provide successful operation of the ozone system.

MAINTENANCE

A routine maintenance schedule has not been implemented to date due to the inoperability of the ozone system. A preventative maintenance schedule is included in the plant's O&M manual, in addition to vendor information. Operator attention and frequency of ozone monitor calibration is also impossible to ascertain at this time due to the inoperability of the system. The plant's

spare parts inventory for the ozone system include compressor parts, gaskets, and dielectric tubes.

OPERATION AND MAINTENANCE COSTS

Detailed ozone production costs are presented in Table 16. Much of the operating data were obtained from performance tests conducted prior to the four months of operation.

Table 16

Brooking's Wastewater Treatment Plant
Ozone System Cost Sheet

O₃ Generation Rate = 26.8 kg/d at 4.05 mg/L
FCI = \$258,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power	35.12	3.0	105
Operating Labor (0.631 MY) (including repair and labor supervision)			100
Repair Materials (1.2% FCI)*			31
Supplies [2% (O.L.)]*			<u>2</u>
Total Operating Cost			238
<u>Overhead Cost</u>			
Insurance			1
Amortization (7% at 20 years)			<u>249</u>
Total Overhead Cost			250
TOTAL OZONE COST ¢/kg (¢/lb)			488 (221)

MY, Man Year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor

*Actual numbers are unavailable and these percentages were taken
from Opatken, E.J., EPA-600/9-79-018, 1979.

MURFREESBORO WASTEWATER TREATMENT PLANT
MURFREESBORO, TENNESSEE

GENERAL

Murfreesboro is located approximately 33 miles southeast of Nashville, Tennessee (see Figure 25). The City's original wastewater treatment plant was constructed in 1971 at a cost of 2.65 million dollars. The plant was expanded in 1979 to a design capacity of 8 mgd at a cost of 8.6 million dollars. The plant's current average daily flow is 4.2 mgd. The wastewater treatment process at Murfreesboro includes aerated grit removal, flow equalization, primary clarification, first-stage pure oxygen-activated sludge, intermediate clarification, second-stage pure oxygen nitrification, final clarification, sand filtration, and ozone disinfection. The plant flow diagram is shown in Figure 26.

The primary purpose for ozonation at the Murfreesboro Wastewater Treatment Plant is disinfection. The ozone system was not on-line at the time the plant visit was made on 25 March 1982. The ozone disinfection system is currently down due to failure of the ozone destruct units. These destruct units are currently being repaired. It should be noted that deficiencies with the ozone system are expected to be corrected within the following year.

The Murfreesboro Wastewater Treatment Plant treats approximately 420,000 gallons of industrial wastewater per day. The major types of industrial wastewater received include hospital, dairy, bakery, and plating wastes. Particular problems are experienced when milk spills from dairy industries are discharged to the City sewer system; this creates excessively high influent BOD concentrations and results in odor problems. In addition, metals and cyanide from plating operations have created biological toxicity problems in the past.

The Murfreesboro Wastewater Treatment Plant discharges into the Stones River, which is water quality limited; therefore, strict effluent limitations have been imposed. Monthly average limits on BOD, ammonia nitrogen, and suspended solids are 10, 2, and 15 mg/L, respectively. Strict NPDES limitations are also imposed for cyanide and heavy metals.

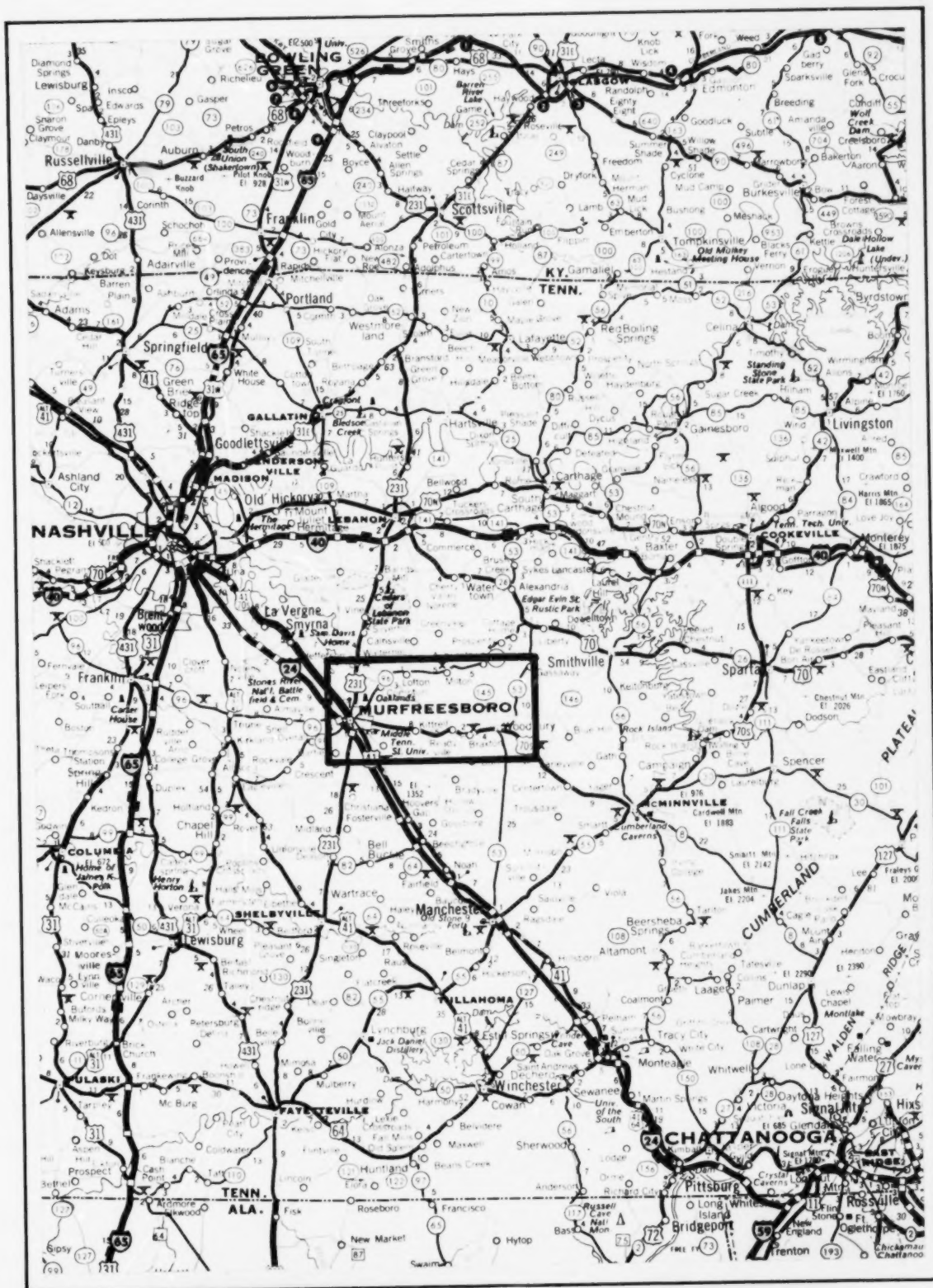


FIGURE 25 PLANT LOCATION MAP

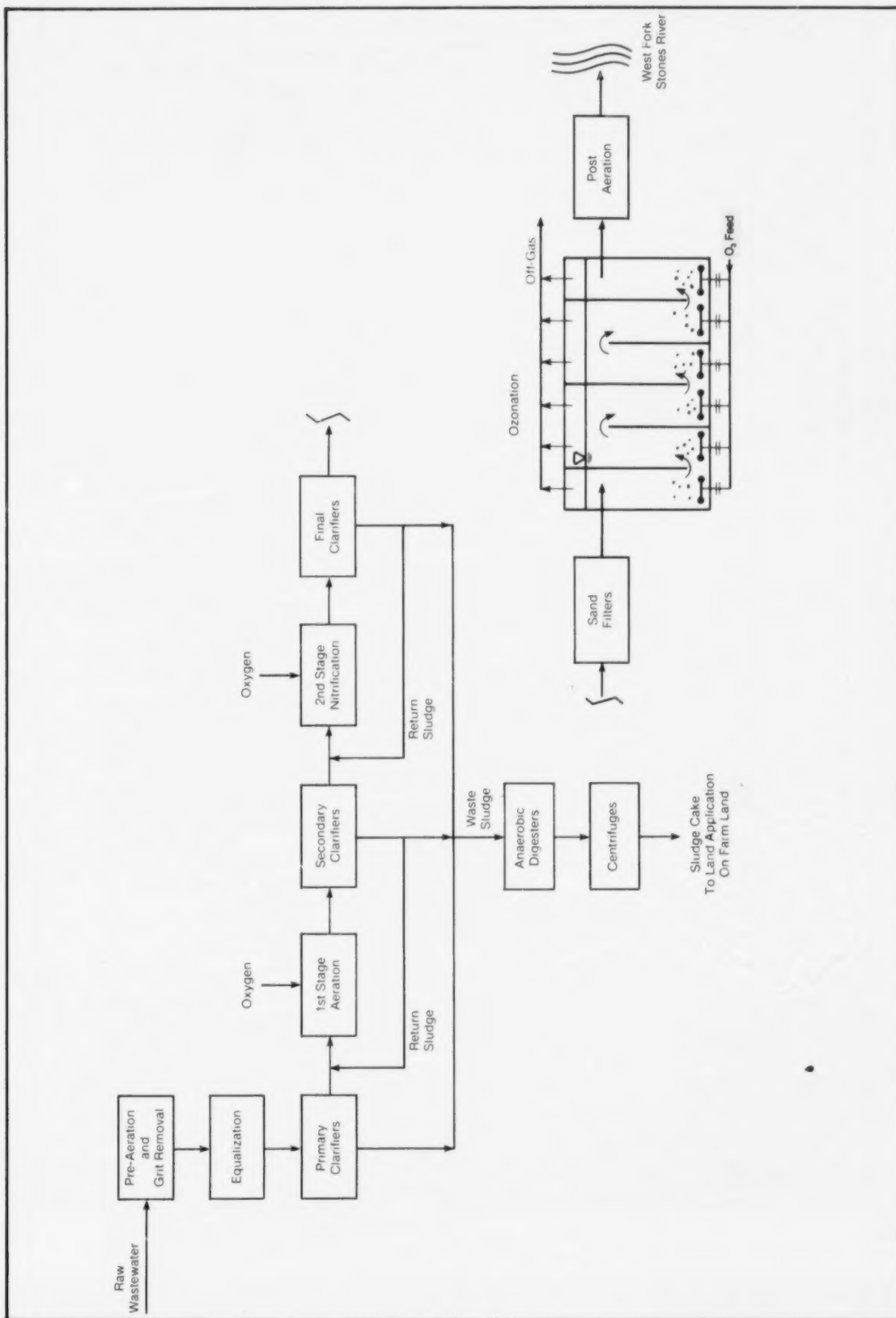


FIGURE 26 PLANT FLOW DIAGRAM

OZONE SYSTEM DESCRIPTION

The ozonation system at the Murfreesboro Wastewater Treatment Plant uses high purity oxygen from their oxygen generation system. Oxygen is passed through Emery ozone generators, and the ozone generated is piped into the plant's ozone contact chamber. The off-gas from the ozone contact chamber is passed through 'oxy-catalyst' ozone destruct units. After the ozone is reconverted to oxygen, it passes through a 'Worthington' oxygen compressor, and the pressure is boosted to approximately 15 psig. The oxygen is then recycled through a desiccant dryer back through the ozone generator. High purity oxygen is used as the feed gas to the ozone generator; therefore, the feed gas already has a sufficiently low dew point. The oxygen inlet pressure is approximately 15 psig at a temperature of 20°C. Air filters are installed prior to the ozone generators. A schematic diagram of the ozone generation system and its interface with the pure oxygen system is shown in Figure 27.

The ozone generators are housed in a separate building which is immediately adjacent to the ozone contact chambers. The facility has three Emery ozone generators (Model 9263) that are tube-type units producing ozone by the corona discharge method. These units are equipped with 72 glass dielectrics which are positioned inside individual stainless steel tubes within a stainless steel outer shell. Cooling water is passed across the tubes on the shell side to remove the heat generated during the electrical discharge. Feed gas for the ozonator can be either oxygen or air dried to a -60°F dew point. A transformer/reactor is supplied with the ozone generator to step up the voltage and adjust the power factor. The ozone production rate is controlled by adjusting the voltage applied to the primary side of the transformer/reactor. The overall dimensions of the ozonator are 3 ft wide by 5 ft high by 11.3 ft long. A transformer/reactor is supplied with the ozonator to step up the voltage from 460 volts to 18,000 volts and readjust the power factor to plus or minus 0.95. The power supply to the transformer has a fixed frequency (60 Hz) and variable voltage.

Each of the three ozone generation units are designed to produce 280 lb per day of ozone. During normal operation, two units are on-line with one stand-by. The daily average output of the system (two units only) is approximately 200 lb per day. The inlet

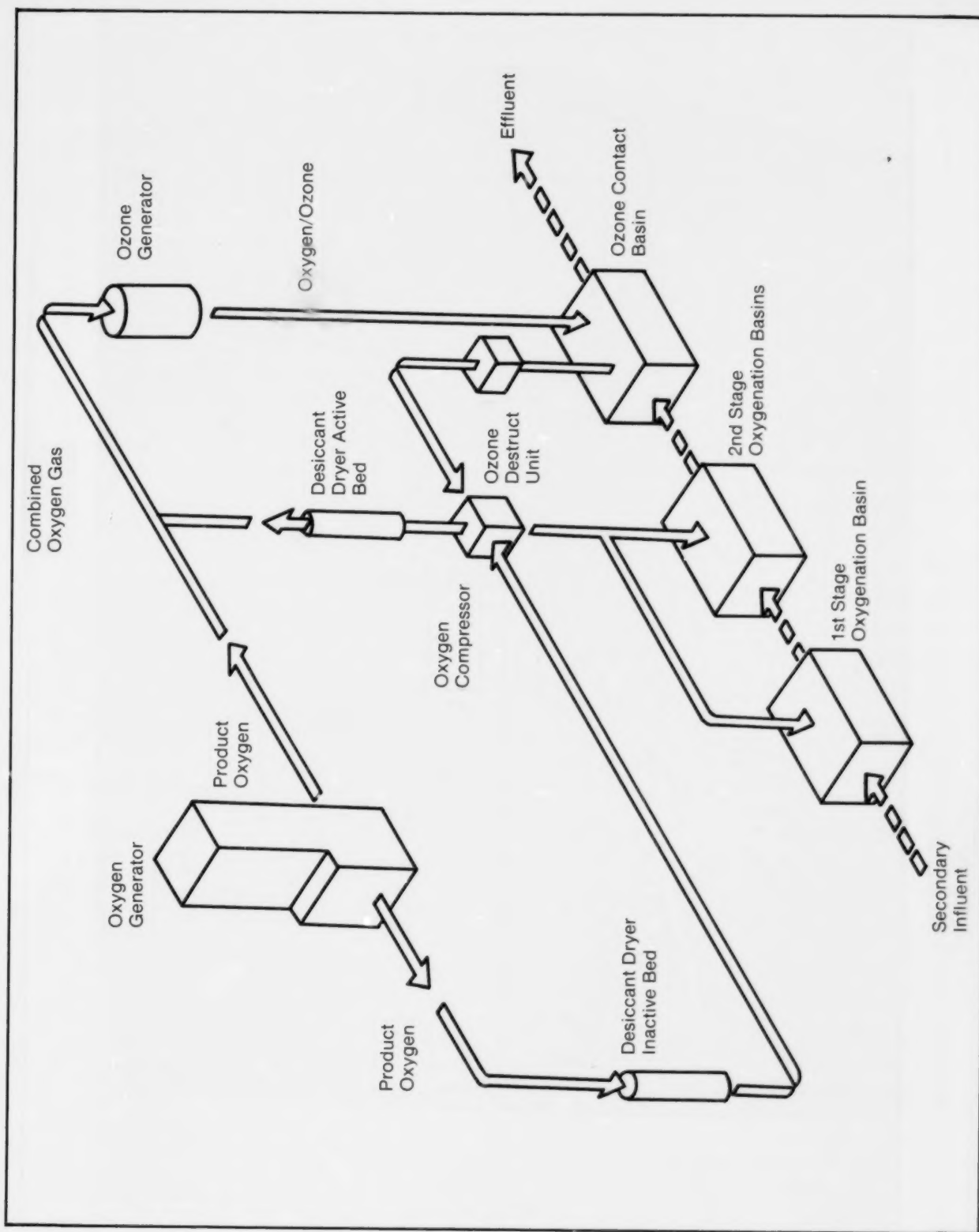


FIGURE 27 OXYGEN AND OZONE SYSTEM

oxygen temperature is approximately 29°C at an average flow rate of 7,000 scfh (the design flow is 14,000 scfh at 560 lb per day ozone capacity). The oxygen supplied to the generator has a dew point of -50°F. Cooling water is supplied to the generator in a closed loop incorporating a cooling tower. The maximum and minimum cooling water temperatures are 35 and 24°C, respectively. Power consumption per kilogram of ozone produced was unavailable due to the very short time the system had been operated prior to being shut down.

The Murfreesboro Wastewater Treatment Plant has two single-stage ozone contact basins. Under normal operation, one is maintained in a stand-by mode. The contactors are completely mixed units with a theoretical detention time of 15 minutes each. Each unit has two pressure relief vents.

The off-gases from the ozone contact chamber are passed through an oxy-catalyst Model CX-8-E Catalytic Oxidation Unit. The off-gas initially flows through a preheater and then is passed over an electric heater which heats the stream to its oxidation temperature (300°F). The gas stream then passes over a catalyst bed which accelerates the chemical reaction that converts ozone to oxygen. The gas is then passed through a desiccant dryer. Two units are provided (one is a stand-by), and they are regenerated using a dry oxygen purge. A schematic of the ozone destruct unit is shown in Figure 28.

Ozone dosage can be controlled both manually and via a flow proportional control loop. On-line UV photometers measure ozone concentration in the discharge streams from the ozonators and the destruct units. These photometers are manufactured by Dasibi. Ozonator inlet dew point is measured by a General Eastern Model 1200 optical condensation hygrometer.

FACILITY OPERATIONS

Ozone System Control

The ozone generators are controlled by adjusting the voltage applied to the primary side of the transformer/reactor. By increasing the voltage applied to the ozonator, the ozone concentration being fed to the ozone contact chamber increases.

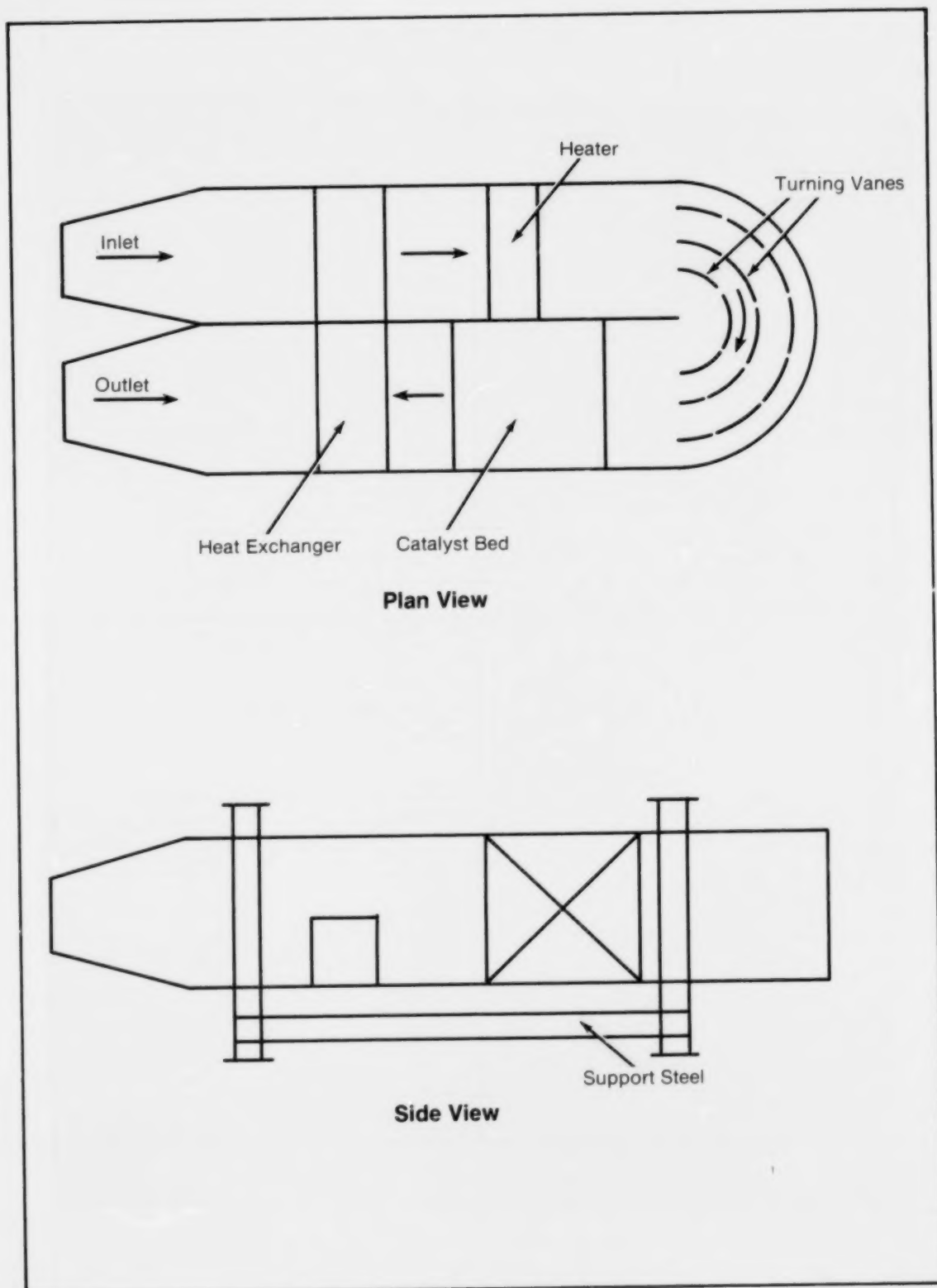


FIGURE 28 OZONE DESTRUCT UNIT

If the voltage to the ozonators is significantly increased, then the oxygen supply to the ozonators must also be increased. Ozone dosage may also be controlled by flow proportioning. An electrical signal is sent back to the ozonators from the plant effluent flow meter. This signal proportionally increases the voltage applied to the ozonators, thus increasing the ozone dosage with increasing flow. However, if substantial quantities of infiltration are being treated by the plant, this method may result in overdosing and wasting of ozone. Since the ozone system only ran for 10 to 12 weeks during initial start-up, no sufficient operational data have been gathered to ascertain the best mode of operation for this plant. It should be noted that the ozonator can also be operated in the manual mode by manually increasing the voltage to the generator via a rheostat, and manually increasing the oxygen gas flow via a control rotameter.

Other operational features include provisions for high-rate purging with dry oxygen prior to start-up. Also, provisions for low-rate purging during stoppage to prevent condensation forming inside the generator are provided. Carrier gas flow detectors for the air and water streams are provided and will shut down the generators in the event that flow stops.

Start-Up and Operational Problems

Since the oxygen and ozone systems are interrelated, single-source responsibility for construction and start-up was required by the specifications for the project. FMC furnished the oxygen system and assumed overall responsibility for the ozone system as well. The ozone system could not be placed in service until the oxygen system became operational. Various mechanical problems delayed progress on the oxygen generator, and the system was not placed on-line until mid 1981.

The ozone generators were tested and found to meet specifications, and the ozone reaction chambers also performed in a satisfactory manner. However, problems experienced with the ozone destruct units have prevented continuous operation of the ozone system, and remedial actions are currently under way.

Extreme foaming in the ozone contactor is the first of two major problems which have disabled the ozone destruct unit. It is believed that foam, carrying with it volatile organic solids, flowed out of the contactor and into the destruct unit and eventually plugged the off-gas vent line. Both the stopping of off-gas flow and the feeding of volatile organic solids are believed

to have caused extremely high operating temperatures in the destruct units. These high temperatures caused the fins on the heat exchanger to melt. The result was extremely poor destruction efficiency, and ultimately a hole was burned through the center wall of the destruct unit (see Figure 28). It is believed that the hole created in the center wall of the destruct unit caused bypassing of the heater and catalyst. In 1981, failure to adequately destroy the ozone caused a complete annihilation of the biota in the first stage activated-sludge basin. Since this time, the unit has been down for modifications and repair.

Ozone leakage around the catalyst beds in the destruct units has also been experienced. It was found that insufficient packing and gasketing around the catalyst bed was allowing ozone to leak around the catalyst bed and, therefore, not be adequately destroyed. At this time it has not been determined as to whether this gasket failure was due to poor fitting, or whether it was due to material deterioration.

The second major problem in the ozone destruct units involved the fouling of the catalyst media by chlorine gas. The catalyst bed was completely fouled within three days following initial start-up of the destruct unit. This fouling appears to be caused by chlorine gas which is stripped from chlorinated organics in the ozone contact chamber. It is believed that the formation of these chlorinated organics occurs during the chlorination process at the City's water treatment plant. The ozone destruct unit manufacturer has proposed, and is currently designing, a caustic scrubber to eliminate the chlorine gas prior to its entrance into the catalyst beds. Additional work is under way to install spray mist eliminators to control foaming and prevent foam from traveling into the destruct unit. The equipment manufacturer estimates that the ozone destruct unit will be back in operation in late 1982 or early 1983.

At this time, the plant's only method for measuring ozone concentration in a gas stream is by UV photometers. These instruments are used primarily for process control and not to determine actual process efficiencies. Wet test methods were used at the site by the equipment manufacturer during the attempted start-up. The equipment manufacturer has not yet supplied the plant with the equipment and/or the procedure necessary for the wet test method of determining ozone concentration. For this reason, no data exist to date on the contactor ozone transfer efficiency; however, adequate sampling ports are currently in place for the determination of contactor efficiencies.

Operations and Maintenance Staff

In the opinion of the plant supervisor, the operators' attitude towards the ozone system and its associated instrumentation is very good; however, operators have not had sufficient time to work with the system. The plant supervisor foresees one or two men being assigned solely to the operation of the ozone system. At this time, a comprehensive evaluation of the ozone system operation and the adequacy of the operators is impossible due to the very short time the system had been on-line prior to the plant visit.

MAINTENANCE

Very little is known at this time about actual maintenance requirements for the ozone system due to the short time of operation. However, the inside of the generator should be cleaned with detergent once a year to maintain operating efficiency utilizing the following steps:

- Shut down the ozonator according to procedures outlined in the vendor manual.
- Remove both generator heads following instructions outlined in the vendor manual.
- Remove the glass dielectrics.
- Blow dust from ozonator shell with dry compressed air.
- Thoroughly wash the interior metal surfaces with detergent, including the metal tubes and the inside of the heads. Rinse with clean water.
- Air blow as much rinse water as possible out of the metal tubes and shell to facilitate drying.
- Remove dielectric spring spacers and then detergent-clean, rinse with clean water, and wipe dry the outside of each glass dielectric.

NOTE: Internals of glass dielectrics should not be removed or detergent-cleaned. Avoid getting water inside glass dielectrics. If inside of dielectrics does become wet during cleaning, allow to dry before ozone generator is put back in service.

In addition to preventive maintenance steps for the ozonator, Table 17 lists the routine maintenance schedule for the entire ozone system. It should be noted that the routine maintenance schedule presented in Table 17 was taken directly from the O&M manual; a working maintenance schedule has yet to be adopted by the plant. Routine maintenance has not been begun by the plant because the system has not become fully operational.

OPERATION AND MAINTENANCE COSTS

Since the ozone system has not been successfully started-up to date, operations and maintenance cost data are not available. A breakdown of the fixed capital investment (FCI) for the ozone system is presented in Table 18.

Table 17

Routine Maintenance Schedule

Routine Maintenance Service		Hours Operation Between Service				
Equipment	Maintenance Service	24 hrs	700 1 Mth	2,000 3 Mths	4,000 6 Mths	8,000 1 Yr
Ozonator Vessel	Clean inside of ozonator vessel and di-electrics by washing with detergent.					X
Ozone Destruct Unit	Check and clean catalyst and economizer heating duct (Q pipe) after first 6 mos.; then, after 1st year, from results of 1st year's performance establish cleaning schedule. Anticipated schedule every 2 to 3 years.					
New York Blower	Clean and inspect, motor permanently lubricated.					X
PTM Desiccant Dryer	Check operating conditions, temperature pressure, flow, etc.			X		
	Check pressure drop across prefilter and after filter. (Normally less than 5 psig.)			X		
	Inspect and clean pilot air filter cartridges.				X	

Table 17
(continued)

Equipment	Routine Maintenance Service Maintenance Service	Hours Operation Between Service				
		24 hrs	700 1 Mth	2,000 3 Mths	4,000 6 Mths	8,000 1 Yr
	Inspect purge exhaust; check valves and clean if required.			X		
	Inspect desiccant and replace if badly broken-up or contam- inated. (Note: des- iccant normally 1/8 in. diameter or larger.)					X
	Inspect and clean or replace check valve seats.					X
	Inspect and clean pilot operated valves and solenoid valves.					X
	Replace after filters.				X	
Dasibi Ozone Monitor	Sample pump-dia- phragm - Replace when flow cannot be maintained at 2 liters/min. or on calendar basis at right.				X	
	Solenoid valve - Replace on as- needed basis or on calendar basis at right.					X

Table 17
(continued)

Routine Maintenance Service		Hours Operation Between Service				
Equipment	Maintenance Service	24 hrs	700 1 Mth	2,000 3 Mths	4,000 6 Mths	8,000 1 Yr
	Ozone scrubber - Replace on as- needed basis. See vendor O&M manual.					
	UV lamp - Re- place on calen- dar basis at right.					X
	General clean- ing of optic system. See vendor O&M manual for in- strument indi- cations of this maintenance.					
Bacharach Oxygen Analyzer	Inspect instru- ment pilot light on.			X		
	Check oxygen reading with O ₂ cell in atmos- pheric air <u>weekly</u> . If reading of 21 percent cannot be obtained by SPAN adjustment, reac- tivate oxygen cell. See vendor O&M manual for additional as- required checks.					

Table 17
(continued)

Equipment	Routine Maintenance Service	Hours Operation Between Service				
		24 hrs	700 1 Mth	2,000 3 Mths	4,000 6 Mths	8,000 1 Yr
Bacharach Combustible Gas Analyzer	Inspect instrument pilot light on. See vendor O&M manual for weekly and monthly test check procedures.	X				
Balston Filters	Change filter element as required when pressure drop across filter is approximately 3 times initial pressure drop.					
General Eastern Dew Point Sensor	Routine cleaning of mirror when balance adjustment cannot bring meter to mid-scale.					
Foxboro Recorders	Refill ink wells. Replace strip charts every 15 days.					X

Table 18

Breakdown of Fixed Capital Investment
for Ozone Disinfection System at
Murfreesboro Wastewater Treatment Plant

Item	FCI \$
Electrical	23,500
Valves, Piping, and Fittings	33,100
Weir Plates	1,000
Instrumentation	1,000
Oxygen Dryer	150,000
Oxygen Compressor	180,000
Cooling Tower	5,000
Ozone Destructor	25,000
Ozone System Transformers	24,000
Ozone System Power Controller	13,500
Ozone Control Panel	30,000
Ozone Generators (3)	207,500
Ozone Purge Blowers	3,000
Ozone Diffusers	27,000
Ozone Field Instru. and Manual Valves	45,000
Oxygen Field Instru. and Manual Valves	30,000
Ozone Motor Control Center	10,000
Process Engineering	110,000
Structural Engineering	70,000
Civil Work	205,500
TOTAL FIXED CAPITAL INVESTMENT	\$1,194,100

MADISONVILLE WASTEWATER TREATMENT PLANT
MADISONVILLE, KENTUCKY

GENERAL

Madisonville is located in the central portion of western Kentucky, approximately 45 miles southwest of Owensboro (see Figure 29). The original facility was a trickling filter plant constructed in 1956. The present pure oxygen plant was constructed between 1978 and 1981 at a cost of 8.5 million dollars. A site visit was conducted on 24 March 1982.

The Madisonville plant (4.5 mgd design flow) currently treats an average flow of 3.9 mgd. The plant's treatment scheme incorporates raw sewage pumping, screening and grit collection, primary treatment via static screens, a two-stage pure oxygen-activated sludge system, secondary clarification (intermediate and final), tertiary filtration, and disinfection by ozonation. The ozone system is currently not being used. The plant's sludge handling system employs aerobic digestion, gravity thickening, and sand drying beds. A plant flow diagram is shown in Figure 30.

The secondary treatment process combines a pure oxygen, high-rate carbonaceous removal system with a second-stage nitrification system. The plant's aerobic digester also uses pure oxygen. All oxygen is supplied by an on-site oxygen generation facility that produces a 90 percent oxygen gas stream.

The plant's final effluent discharges into Flat Creek, a tributary stream which flows into Pond River. The nearest downstream community is Jewel City, Kentucky, which is located approximately 35 miles from Madisonville. The estimated 7-day, 10-year minimum flow for Flat Creek is zero flow, thus stringent NPDES discharge limitations have been imposed on the Madisonville plant. The plant's discharge limits are presented in Table 19.

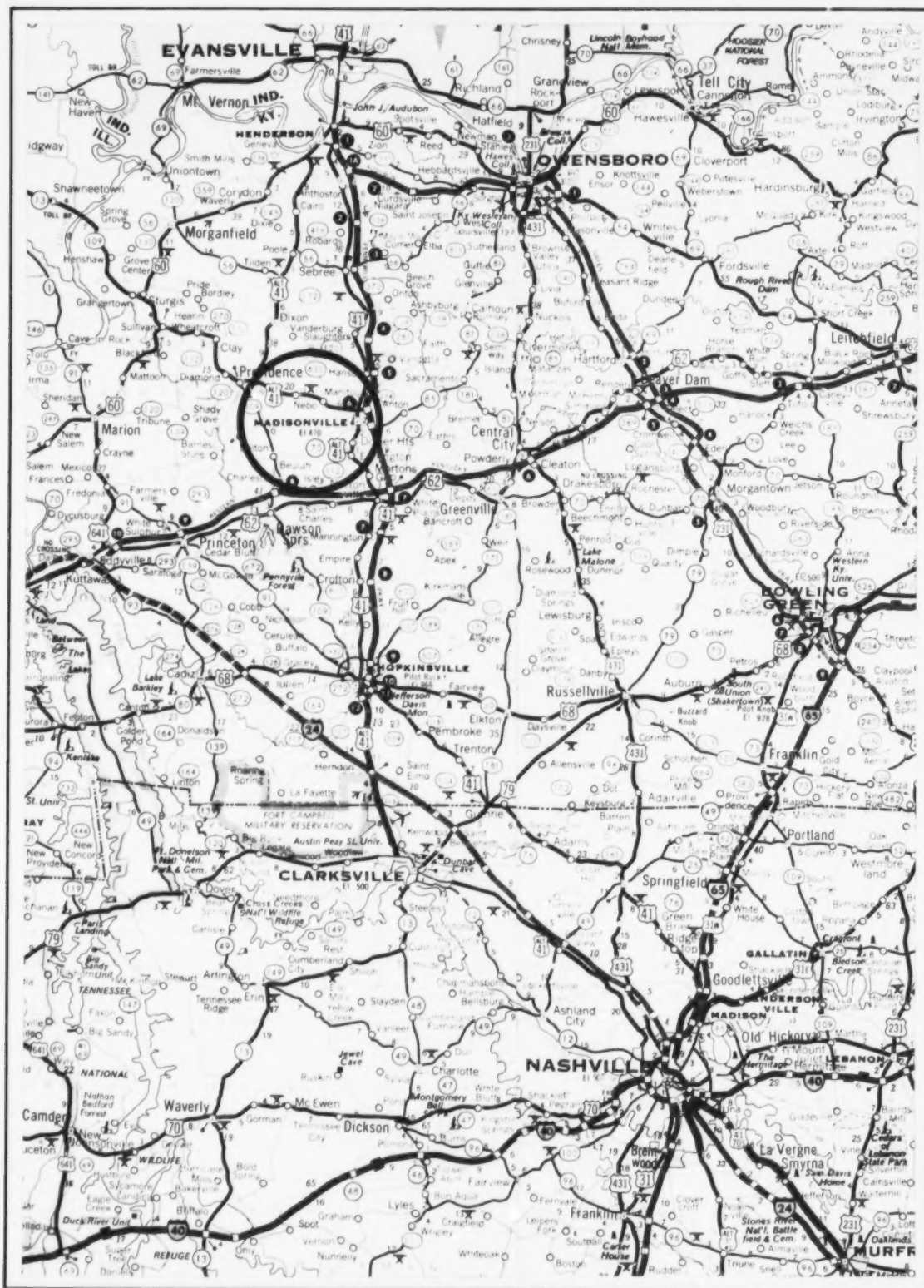


FIGURE 29 PLANT LOCATION MAP

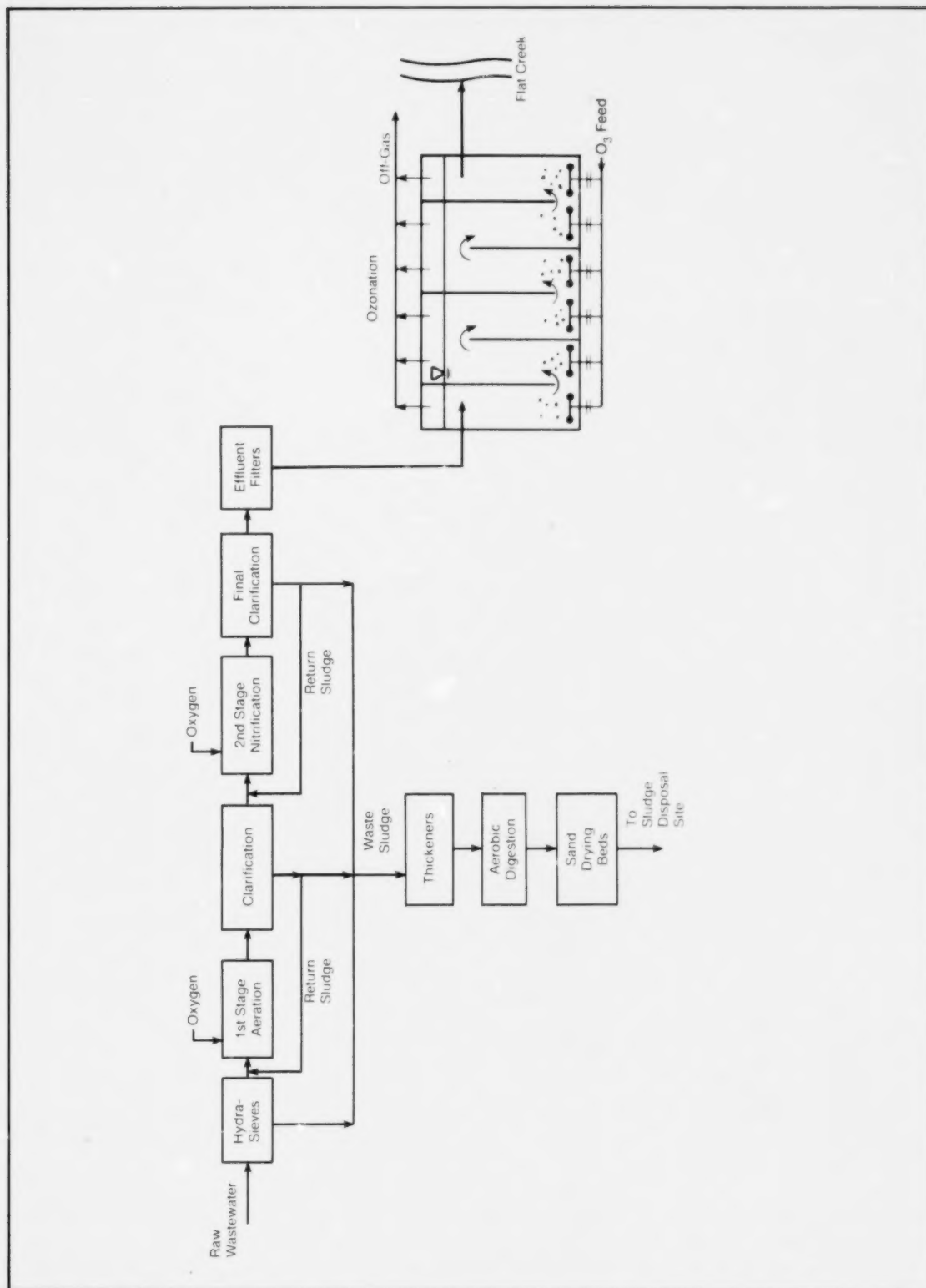


FIGURE 30 PLANT FLOW DIAGRAM

Table 19

NPDES Discharge Limitations
Madisonville Wastewater Treatment Plant
Madisonville, Kentucky

Parameter	Discharge Limitations	
	Monthly Average	Weekly Average
Flow	4.5 mgd	---
BOD ₅	10 mg/L	15 mg/L*
Suspended Solids	30 mg/L	45 mg/L*
Fecal Coliform	200/100 ml	400/100 ml
Ammonia Nitrogen	1 mg/L	7 mg/L
Dissolved Oxygen	7 mg/L	7 mg/L

*Or 85 percent removal, whichever is most stringent.

OZONE SYSTEM DESCRIPTION

The Madisonville plant utilizes an ozonation system for disinfecting filtered effluent. The 11 tpd on-site oxygen generation system (i.e., part of the pure oxygen activated sludge facility) supplies all oxygen required by the ozonation process. Oxygen is fed to three Union Carbide (one is a spare) LG-90 ozone generators, each rated at 140 ppd. One generator is required for average flow conditions, and two are for peak conditions. Generated ozone (2.2 to 3.1 wt percent) is fed into two contactors. Each contactor has internal dimensions of 13.8 ft x 13.8 ft x 19 ft, with a side water depth (swd) of 16.5 ft, which provides a liquid volume of 23,500 gallons and an associated detention time of 15 minutes at design flow.

Ozone that collects in the top of the contact chambers is vented to destruct units. A foam suppression nozzle system installed at the inlet of the contactor vent line prevents any foam that may have been produced in the contact tank from entering the gas vent. In addition, the vented gas also passes through a stainless-steel mesh demister that prevents water and foam from being carried into the downstream ozone destruct units. Two catalytic ozone destruct systems decompose the ozone, and the resultant oxygen is compressed and recycled to the nitrification basins. The ozone system and its interface with the pure oxygen system is shown in Figure 31.

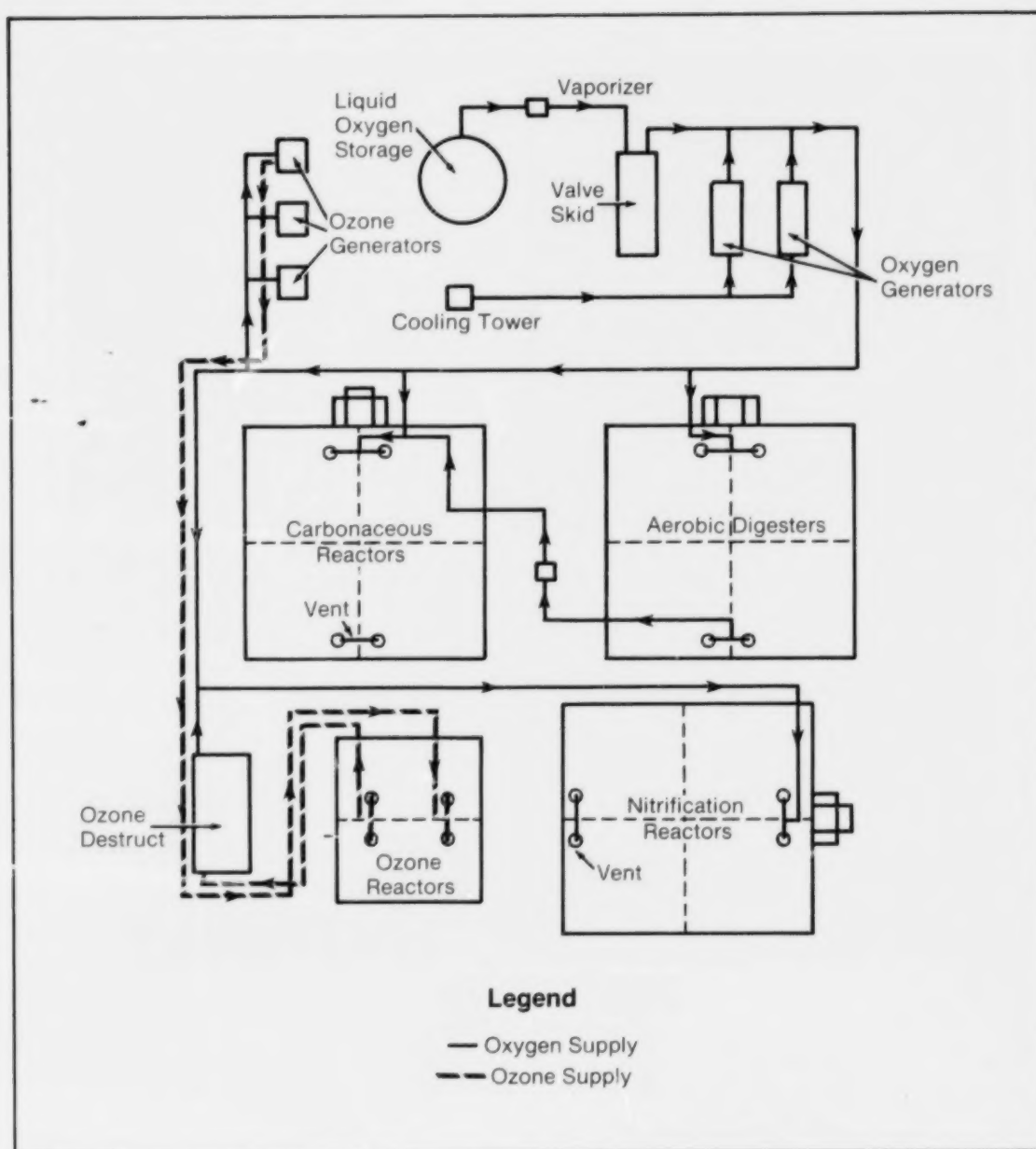


**FIGURE 31 MADISONVILLE OXYGENATION SUPPLY SYSTEM
OZONATION SYSTEM SCHEMATIC**

Two Sieman and Hinsch, Model KPH-5216, single-acting, liquid ring compressors are provided as ozone boosters. Only one compressor is operated at a time, the second being a spare. Each compressor is rated to deliver 200 cfm of ozone from a suction pressure of 14 psia to a discharge pressure of 15.64 psia. The compressors are driven by 20-hp, 1,750-rpm, 3/16/460-volt TEFC electric motors and are equipped with a suction filter, water separator, and water trap.

Three Union Carbide LG-90 ozone generators are installed in the plant's ozone generator room. At design conditions, (1 unit at 104 scfm) each generator will produce 140 lb per day of ozone.

Two catalytic ozone destructors, manufactured by Mine Safety Appliance Company, are provided to decompose ozone which has not been adsorbed in the ozone contactors. Only one destructor is operated at a time, the second being a spare. Each unit is rated for an input of 111 cfm (the maximum design flow is 113 cfm).

Combustible gases are purged from the contactor by one American Fan Company, Model AVP-4-10-17B, centrifugal blower. The blower is rated for 63.5 cfm and is driven by a 5-hp, 3,600-rpm, 460-volt TEFC electric motor.

The main ozone panel, located in the ozone generator room, contains the major controls and instruments used to monitor and regulate gas flows to the ozonation system. It also contains the annunciator alarm panel.

The ozone analyzer panel, which is located near the booster compressors and destruct units, contains the sampling systems and controls for analysis of samples from the destruct units and from the vent duct. The sample pumps, sample control piping, and related equipment are located inside the panel.

FACILITY OPERATIONS

Ozone System Control

The operator has control of two process variables:

1. The flow of ozone to the contactors.
2. The ozone concentration in the oxygen-ozone stream.

The ozonation system at Madisonville, Kentucky was designed to provide a dose of 6 mg/L ozone to the wastewater. The plant's contactors are operated in parallel.

Ozone is injected into the plant effluent via porous ceramic diffusers in both contactors. Gas flow to the first contactor can be adjusted separately from that to the second contactor in order to permit tuning of the process for maximum ozone utilization.

The ozonation system feed rate is automatically controlled according to wastewater flow. The oxygen flow to the ozone system, and the output of ozone from the generators, is increased and decreased proportional to wastewater flow rate.

Any residual ozone in the vented gas from the contactors is converted to oxygen as the gas is passed through a catalytic ozone destruct unit. This oxygen is recycled back to the nitrification system.

The ozone concentration in the gas stream is controlled by the capacity-control signal driving the ozone generators. The capacity-control signal may be either manually set or automatically adjusted in response to the wastewater flow rate through the contactors; greater liquid flow produces a higher capacity signal, and reduced liquid flow produces a decreased capacity signal. The proportionality of these flows is adjusted at the time of initial start-up to produce a 2.2 or 3.1 percent (by weight) ozone concentration regardless of oxygen feed flow. Other ozone concentrations can be obtained by manual control of generator capacity.

Start-Up and Operational Problems

The Madisonville ozone system was only operated for approximately three months (3 April to 7 July 1981) before it had to be shut down. The major reason for shut down was that generator room temperatures were consistently around 140°F. This very high room temperature made working conditions extremely difficult for plant operators. The problem originated because room air was supposed to cool the ozone generators. The ozone generator room is presently being modified to allow using outside air to cool the generators.

Another difficulty experienced during start-up involved the flow proportional, ozone dosage control strategy. While in the automatic flow proportional mode, the generation system was overdosing ozone due to substantial quantities of infiltration during wet weather. For this reason, the ozone system had to be operated in the manual mode. At the present time, the contractor has offered no other solution to this problem other than to operate the system in the manual mode.

No data were available for determining the contactor ozone transfer efficiency during the three months the system was on-line. However, there are adequate sampling ports in-place for measuring inlet and outlet gases around the ozone contactor. The current method of analyzing ozone is by on-line UV photometers and wet chemical methods for aqueous ozone residual. The UV photometers are currently being calibrated electronically. The plant doesn't have the capability to analyze ozone gas streams by the iodometric wet test method.

Operations and Maintenance Staff

Operator motivation and interest in the ozone disinfection system appeared to be excellent during the plant visit. The operators' understanding of the process seemed to be more mechanical than technical, and they seemed to be rather intimidated by the process instrumentation. Considering all of the above limitations, the plant supervisor feels that once the design deficiencies are corrected, the operators should be able to adequately run the disinfection system.

MAINTENANCE

A routine maintenance schedule has not been implemented to date because the disinfection system has not been successfully started up. In addition, a spare parts inventory for the ozone system has not been compiled. However, the following periodic maintenance checks are listed in the plant's O&M manual and vendor information manual.

It is recommended that the following tasks be performed on a daily basis. Experience may dictate more or less frequent checks.

- Check contactor relief valves to ensure they are not weeping (neither inward nor outward flow of gas).
- Check automatic drain traps on condensing coils at each sample pump.
- Note sound of each compressor; check per manufacturer's instructions if any compressor sounds abnormal or suspect.

- Check seal water supply of operating booster compressors; look for any abnormalities; take corrective action before alarms or shutdowns make such actions mandatory.
- Examine records of ozone production; schedule generator switchover ahead of normal schedule if a generator is performing poorly.

Weekly checks include the following items. Experience may dictate more or less frequent checks.

- Check calibration of ozone analyzers.
- Check ozone destruct units for differential pressure; switch out units and replace filters when pressure differential exceeds manufacturer's recommendations (see yearly checks).

Each month, one operating booster compressor should be shut down and the spare unit started-up in its place. Every three months, using a portable ozone analyzer, the valves listed herein should be checked for ozone leakage. If an ozone concentration of 0.1 ppm (volume) can be detected at a distance of 1 ft from the valve, the valve must be repaired or replaced. Valves to be checked for ozone leakage are as follows: ozone generator isolation valves; high concentration ozone sample valves; disposal pressure valves; generator back pressure valve; contactor purge valves; ozone contactor isolation valves; ozone contactor sample valves; ozone contactor pressure valves; and ozone disposal device isolation valves.

Once a year the ozone catalyst in each ozone analyzer should be replaced to maintain instrument accuracy.

OPERATIONS AND MAINTENANCE COST

Operations and maintenance costs could not be formulated because the system is currently not in operation and no data were collected during the very short period of operation.

MONROE WATER TREATMENT PLANT
MONROE, MICHIGAN

GENERAL

The City of Monroe is located in the southeastern portion of Michigan, approximately 30 miles south of Detroit. Monroe lies on the western shore of Lake Erie on Interstate Route 75. A location map is shown in Figure 32.

The Monroe Water Treatment Plant was first brought on-line in 1923 at a design capacity of 4.0 mgd. The facility was subsequently expanded in 1949 and again in 1972 to its present design capacity of 18.0 mgd. The plant currently treats an average daily flow of 7.0 mgd and a maximum daily flow of 11.0 mgd. The ozonation system was added to the treatment scheme in conjunction with the 1972 expansion of the facility, which included a complete renovation of the 50-year-old filtration plant.

Evaluation of alternative odor control techniques indicated that ozone would most effectively reduce or eliminate the strong, objectionable odors exhibited by the waters of Lake Erie and generated in the 200 miles of city water-distribution mains. The plant's ozone system was started-up in February 1979 and has an ozonation capacity of 450 lb/day.

The effectiveness of ozonation for taste and odor control in western Lake Erie waters was verified by pilot testing. The pilot tests indicated that ozone, applied in an amount providing a trace residual at the outlet of the contactor, would effectively destroy all odors and tastes occurring under routine operating conditions. This required a dose that varied seasonally from 0.5 mg/L to 1.5 mg/L. To accommodate higher ozone demand due to the varying water quality of Lake Erie, the expected requirement was doubled for design purposes and the ozonators were sized to produce 450 lb/day to provide a dosage of 3 mg/L of ozone at the design flow of 18 mgd. The primary objective of ozonation was odor and taste reduction; however, various supplementary benefits of ozonation were realized with the destruction of odor and taste. These included partial or complete disinfection, coagulation of colloids, enhanced alum flocculation, better settling, cyanide destruction, and reductions in chlorine demand.

A facility flow diagram is shown in Figure 33. The water treatment process includes initial ozonation followed by primary clarification, multi-media filtration, and on-site storage prior to high service (pressure) pumping through the distribution system.

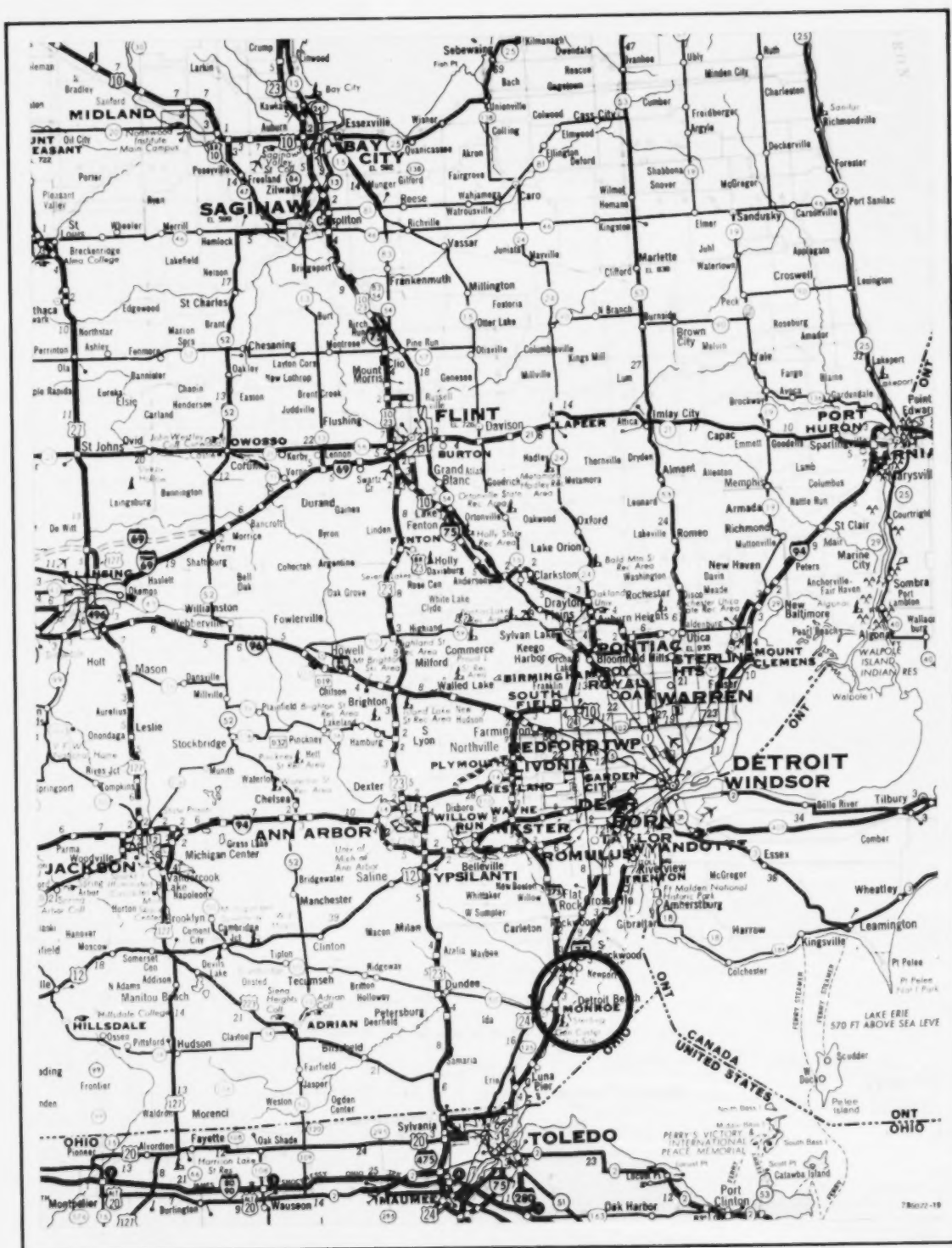


FIGURE 32 PLANT LOCATION MAP

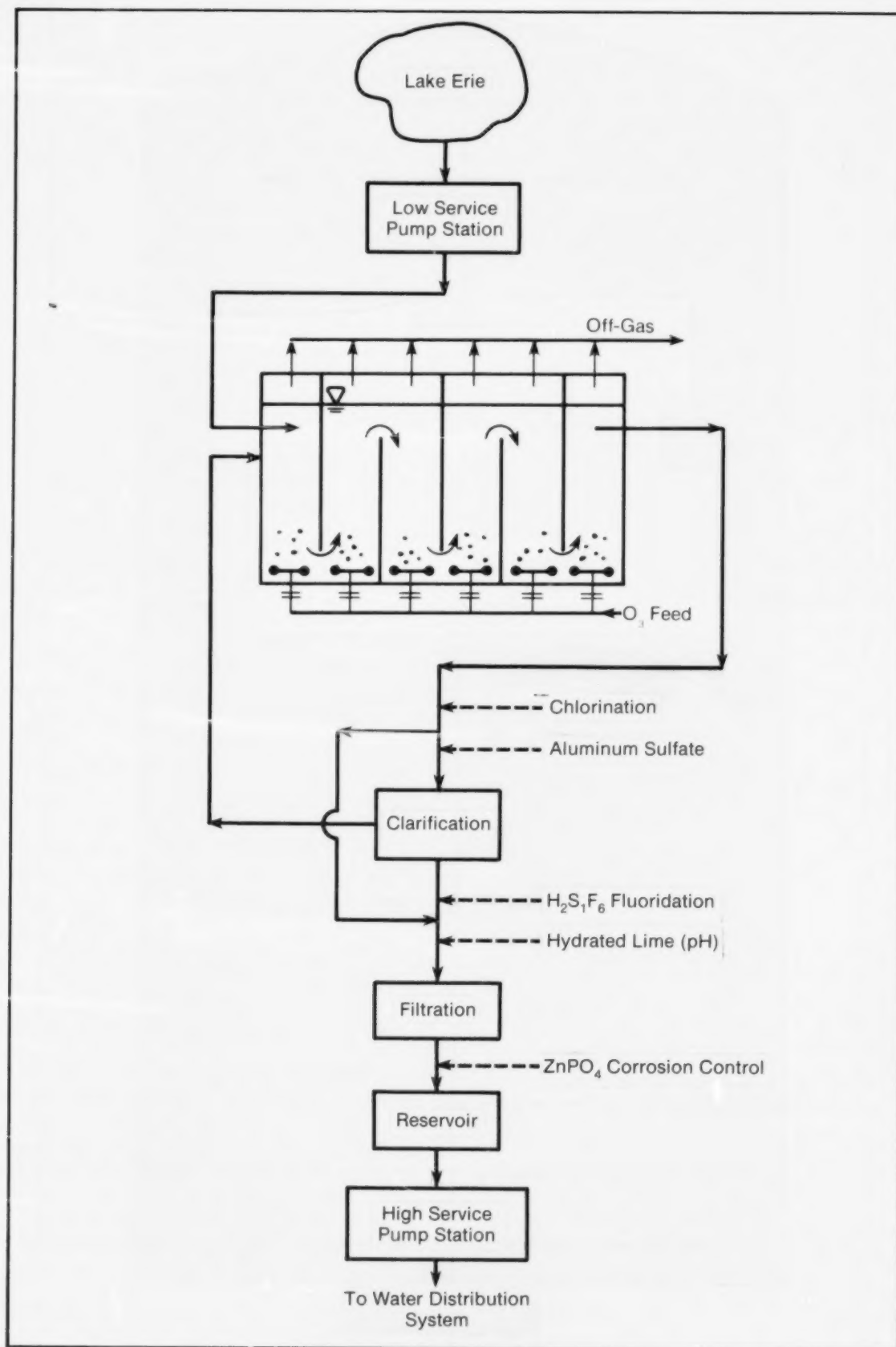


FIGURE 33 PLANT FLOW DIAGRAM

OZONE SYSTEM DESCRIPTION

The ozonator system is a PCI Ozone Corporation Model B-225. Each ozonator system consists of an ozone generator, air preparation unit, and controls mounted on a single skid. Ozone is produced in two high-frequency corona discharge ozonators, each rated at 225 lb of ozone per day at concentrations up to 1 percent by weight, using air as feed gas. Input power requirements are 480-volt, 200-amps, 3-phase, 60-cycle service, with a maximum symmetrical interrupting capacity of 14,000 amps. Each ozonator contains 42 oil cooled, tubular corona cells.

The operating parameters for the ozone units are as follows:

- Ozone Output - 20 to 225 ppd.
- Ozone Capacity - 225 ppd at 1 percent (weight) concentration.
- Air Flow - 110 to 220 scfm.
- Air Purge - 9 scfm.
- Dew Point - Minus 60°F or lower.
- Cooling Water - 52 gpm, maximum temperature 70°F, maximum pressure 75 psig.
- High Voltage Coolant - Internal high voltage coolant oil, capacity 140 gallons.
- Ambient Temperature - 40 to 100°F.
- Ozone Output Control - Local or automatic.

A flow sheet for the ozone system is shown in Figure 34.

The feed gas (air) to the ozonators is filtered to remove particulate matter and moisture. The air compressor is an MD Neumatics, Inc. Model 46-4009. The unit is a lobe-type, rotary, two-stage, positive displacement blower with a 30-hp motor. It delivers 230 scfm of air at a discharge pressure of 18 psig. A compressor after-cooler is used to reduce the discharge air temperature. The air cooler is an air/water heat exchanger that will reduce the temperature of the air leaving the blower to within 15°F of the cooling water temperature. A refrigeration

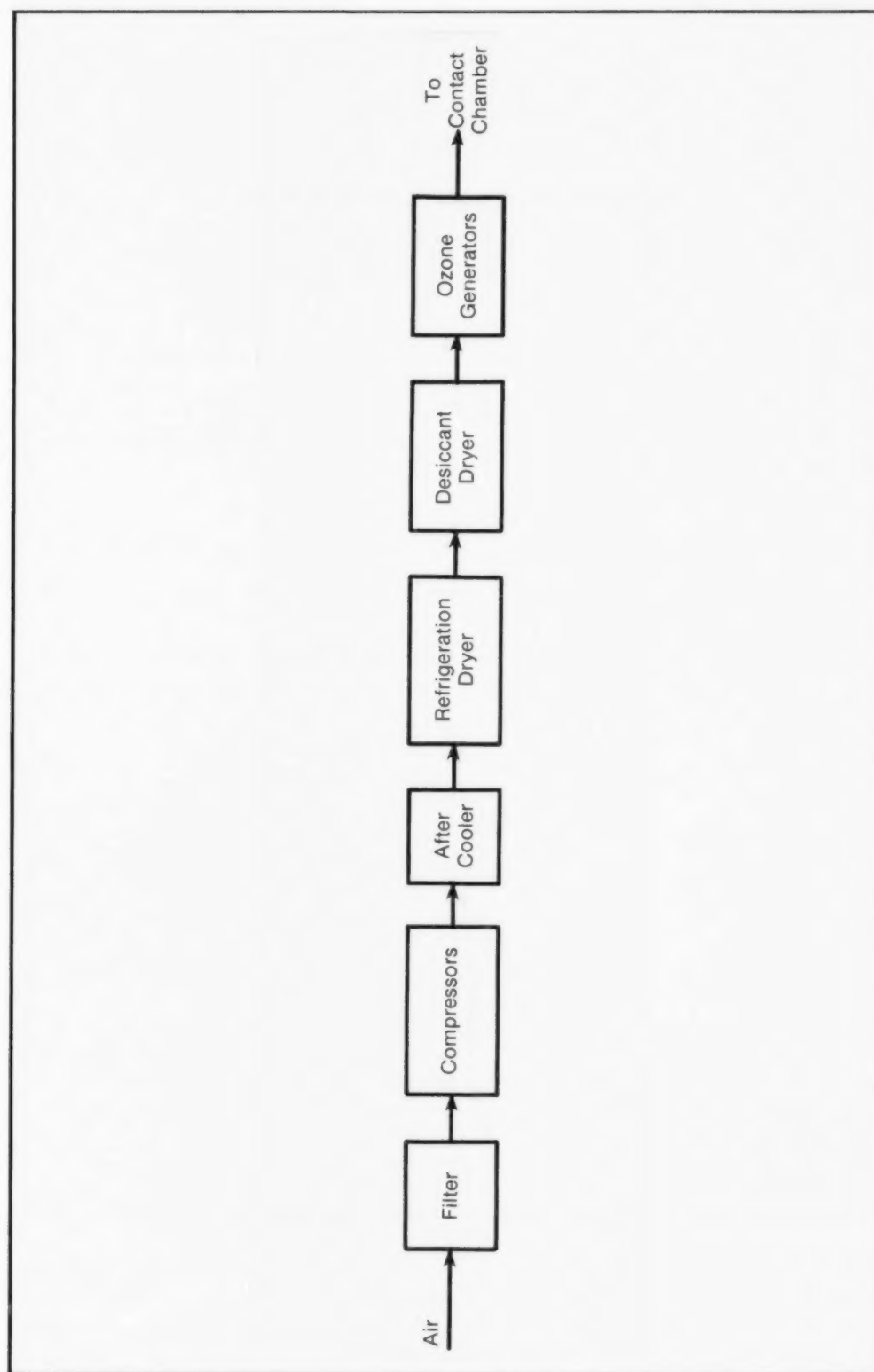


FIGURE 34 OZONE SYSTEM FLOW DIAGRAM

dryer, Kemp Model RF800, further reduces the dew point of the air leaving the compressor to -40°F . From the refrigerant dryer, the air passes through a regenerative-type desiccant dryer that uses molecular sieves and silica gel to further reduce the dew point to -60°F . The desiccant dryer is a Kemp Model 200 and can handle 220 scfm of air at a dew point of -60°F or lower. The dryer has two towers which contain molecular sieves, aluminum balls, and silica gel. The dryer operates on an eight-hour cycle. One tower dries air during the entire eight-hour cycle while the other tower regenerates. To regenerate the dryer, a 6.5 kw heater (which is controlled by a thermostat) heats the dryer to a maximum temperature of 350°F .

The tower is heated for a maximum of four hours and is then cooled for a minimum of four hours. After eight hours, the auxiliary compressor activates a pneumatic valve which causes the dryer towers to switch, and re-starts the eight-hour cycle on the opposite tower. The dryer operation is fully automatic.

Each ozonator houses six bundles that contain seven dual-cooled, tubular corona cells (a total of 42 cells). Each bundle consists of seven stainless steel electrodes and seven silver-plated glass electrodes which are surrounded by a fiberglass shroud. Dry air, which is converted to ozone, passes through an air gap between the stainless steel and glass electrodes. Cooling water flows inside the stainless steel electrode, and a high-voltage coolant oil flows between the glass electrode and the fiberglass shroud to cool the cell (see Figure 35). Each cell is designed to produce 37.5 lb/day of ozone.

The ozone system includes two high-voltage coolant pumps supplied by March Manufacturing. One pump is used to circulate the high-voltage coolant oil through the cells and the other is used to cool the components in the electronics cabinet. There are two heat exchangers associated with the high-voltage coolant oil system. The first heat exchanger, an American Standard Model 5-144-06-066-004, is an oil/water heat exchanger. It is used to cool the high-voltage coolant oil that is circulated through the corona cells. The other heat exchanger is an American Standard Model 5-142-03-024-015. This heat exchanger is also an oil/water heat exchanger and is used to cool the high-voltage coolant oil that is circulated through the electronics cabinet.

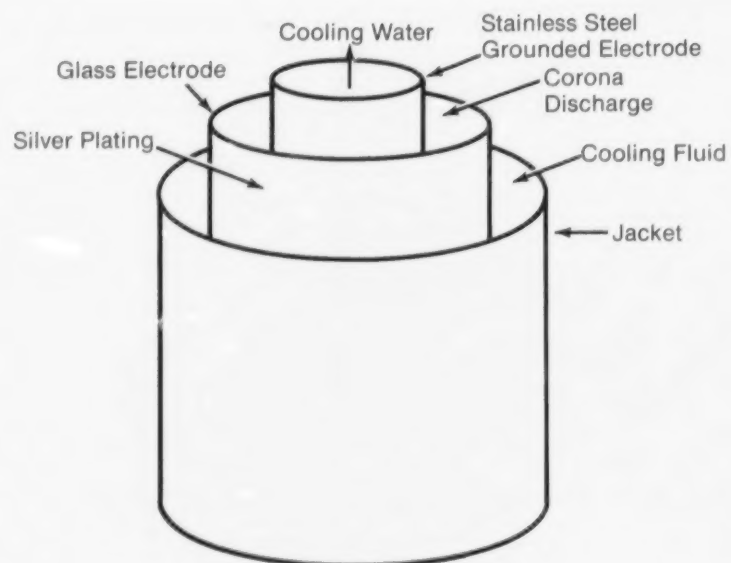
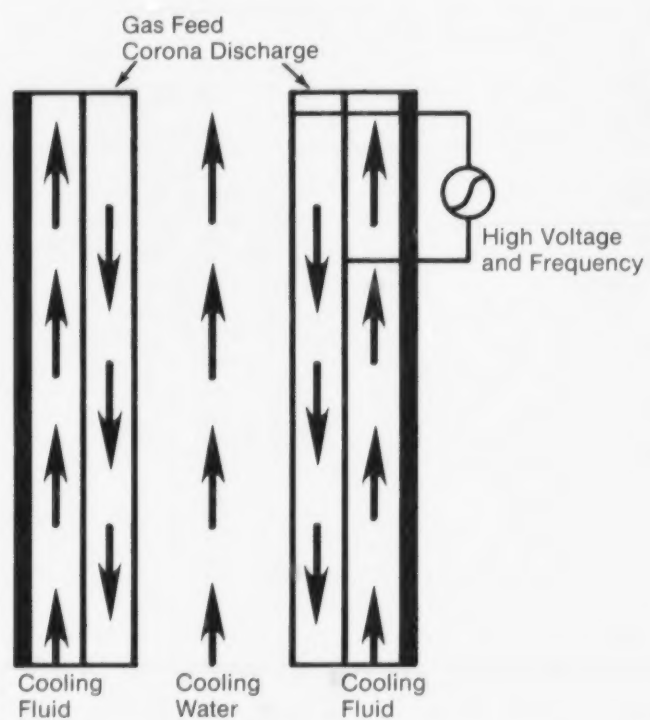


FIGURE 35 OZONE GENERATING CELL

The electronics cabinet contains an inverter circuit and the ozonator controls. The AC input power is rectified to DC and is then reconverted to AC by the inverter. The ozone output is adjusted by varying the frequency from the inverter. The high-voltage transformer has a rating of 244 kva. The primary is fed from the inverter. The rms voltage is approximately 8,000 volts. The high voltage is utilized to generate the ozone in the tubular corona cells.

The ozonized air discharge from the generators is piped to the contact chamber. The contact chamber is located on the lower level of the ozone systems building and houses a counter-current, gas-diffused, positive-pressure recirculating contactor. The contact chamber arrangement is illustrated in Figure 36.

The operating water depth in the contactor is 14 ft, and the detention time is approximately 10 minutes at the design flow rate of 18 mgd. The carrier gas blowers furnished as part of the ozonators maintain pressure above the water in all stages at 1.8 psig. A capacitance probe measures the water depth in the chamber and transmits a 4 to 20 ma DC signal proportional to the water level to a level controller. The controller has a 3 to 15 psi output to position a pneumatically-operated pressure control valve which maintains the desired water level in the contact chamber.

Ozonated air is diffused into the water through a system of 352 porous aluminum oxide diffusers, each 2.5 in. OD by 1.75 in. ID by 24 in. in length.

The contactor has two passes with three stages in each pass. Sixty to 70 percent of the ozonated air containing 1 percent ozone is diffused in the first stage of pass one, and the remaining 30 to 40 percent is diffused in the second stage of pass one. The flow of ozonated air to these two stages is monitored and subsequently regulated as desired by adjustment of two butterfly valves in the carrier gas stream.

All of the exhaust air from pass one is collected, recompressed, and recycled to pass two where it is diffused into the raw water not yet ozonated. This effectively uses all the ozone produced and minimizes the amount of ozone remaining in the off-gas from pass two as it is discharged to the atmosphere.

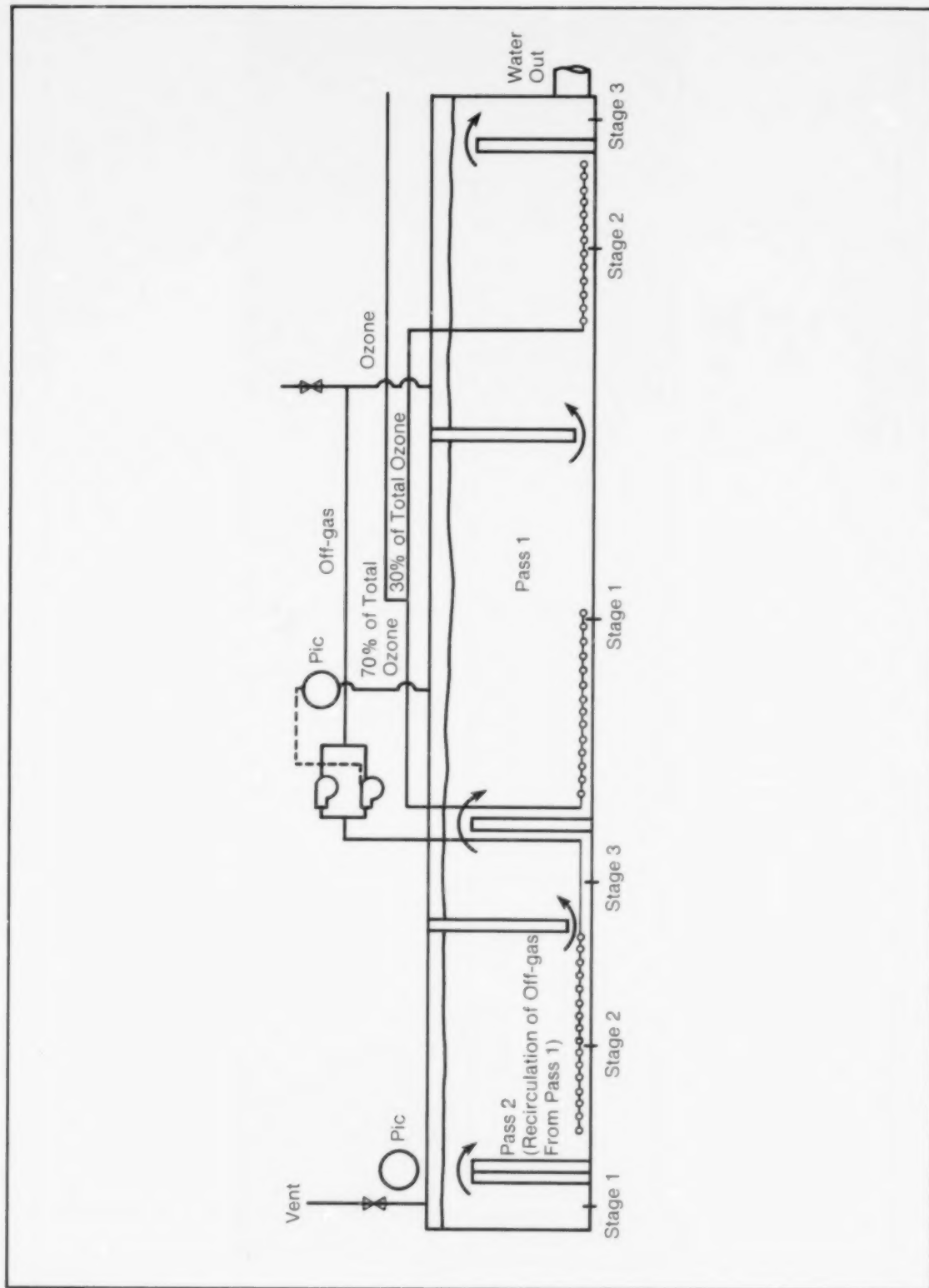


FIGURE 36 SCHEMATIC OF OZONE CONTACTOR AT MONROE WATERWORKS

Additional instruments supplied with ozone equipment include the following:

- Dew Point Hygrometer - The dew point hygrometer measures the absolute humidity of the air to the ozonator cells. It has the capability of measuring dew points in the range of -100°F to 140°F. The unit has an automatic self-standardization cycle which minimizes maintenance requirements.
- Air Flow Meter - This flow meter measures the air flow rate to the ozonator cells. It reads directly in scfm in the range of 0 to 300 scfm.
- DC Ammeter - The DC ammeter measures the DC current to the inverter in the ozonator. The DC ammeter measures in the range of 0 to 150 amps. The ammeter measures the current to the inverter, which is proportional to the ozone output of the unit. When an increase in ozone output occurs, it usually means the controller has called for more ozone because of water quality fluctuations.

FACILITY OPERATIONS

Ozone System Control

As previously described, the purpose of ozonation at the Monroe facility is to reduce or eliminate taste and odors associated with the waters from Lake Erie. Control of the system may be effected in two ways. The AC input power is rectified to DC and reconverted to AC by a pulse generator that is controlled by an external 4 to 20 ma signal. This signal originates in the automatic control cabinet where an amperometric analytical instrument (Fisher & Porter residual ozone analyzer Series 17L2000A) continuously measures the residual ozone at a selected control point inside the contact chamber. It produces a 4 to 20 ma DC output signal that is directly proportional to the ozone residual in mg/L. The signal is applied to a controller that compares the measured ozone residual with the desired residual and emits a signal that is used to adjust the ozone output.

The output of the ozonators may also be controlled by a 4 to 20 ma signal based on the metered water flow to the contactor. This system will maintain a pre-set, constant rate of ozone application regardless of variations in water flow rates. Both systems

are very responsive; however, control by ozone residual in the contact chamber is the method preferred by the operating staff.

The system mode of operation is selected by a four position rotary switch which determines the manner in which the ozonators produce the required ozone. The four modes of operation available include:

- System Off - The ozonator system is off.
- Number 2 Lead, Number 2 Lag - Only Ozonator Number 1 will operate if the required amount of ozone is 50 percent or less of the total capacity of the two ozonators. If the required amount of ozone is greater than 50 percent, Ozonator Number 1 will operate at full capacity and Ozonator Number 2, the "slave" in this case, will automatically start and pick up the additional ozone needed.
- Number 2 Lead, Number 1 Lag - The roles of Ozonator Number 1 and Ozonator Number 2 are reversed.
- Number 1 Lead and Number 2 Parallel - Ozonator Number 1 and Ozonator Number 2 will each produce half of the required ozone.

A set-point control station has been provided and is used to set the desired ozone residual in the contact chamber. In the automatic mode, when the dosing control is in RESIDUAL and the automatic button is pushed in, the output of the ozonator is controlled automatically to maintain a constant ozone residual in the contact chamber. In the manual mode, when the dosing control is in RESIDUAL and the manual button is pushed in, the output of the ozonator may be controlled manually at the automatic control cabinet. To control the ozone output manually, the appropriate push buttons are used. The ozone output of the ozonators will be as follows:

- If the system mode is lead-lag, only the lead ozonator will be producing ozone if the indicator is less than 50 percent. If it is greater than 50 percent, the lead ozonator will be operating at full capacity and the lag ozonator will produce the additional required ozone.

- If the system mode is 1 and 2 parallel, the two ozonators will be producing the same amount of ozone. They will be at full capacity when the indicator is at 50 percent.

There are several flow sensors which are associated with the unit to monitor the operating status of the system. The flow sensors are:

- Flow Meter -- Ellison Annubar Model 77B. This measures the air flow rate to the ozonator cells. If the air flow is less than the set point shown on the flow meter, the system shuts down.
- Temperature Sensor (the Number 2) -- Burling Model Bl-C. One senses the temperature of ozone leaving the ozonator; if the temperature is greater than 150°F, the high ozone temperature interlock goes on. The other senses the temperature of the cooling water entering the ozonator; if the temperature is greater than 70°F, the system shuts down.
- Flow Switch -- Delta Model 604. The flow switch senses the cooling water flow. If the water flow rate is less than 20 cpm, the system shuts down.
- Flow Switch (the Number 2) -- Delta Model 614. This senses the high-voltage coolant flow to the cells and to the electronics cabinet. If the oil flow rate is low, the system shuts down.

Instrumentation has been supplied to continuously measure the ozone concentration in the carrier gas stream, the ozone residual in the raw water, and the ozone concentration in the contactor off-gas. The high concentration gas phase analysis was initially accomplished by the wet chemistry, neutral KI method. This procedure was replaced with the installation of the continuous reading, high concentration (0 to 10 percent by weight) ozone monitor that measures ozone by the ultraviolet (UV) absorption technique. Gas phase analysis is performed primarily to measure ozone concentrations in the carrier gas stream and in the off-gases from the diffusion stages of the contactor.

Ambient air monitors continuously check the environment within and around the ozone systems building. If the ozone concentration reaches a preset level, usually 0.1 ppm by volume, the ozonators are shut off, an alarm is sounded through the plant

enunciator system, and the automatic ventilation system is activated. The alarm condition must be corrected before the ozonators can be restarted.

Start-Up and Operational Problems

Since the ozonators had been tested extensively by the manufacturers before acceptance and delivery, start-up of the system was reasonably trouble-free. Hydrostatic tests of the ozone generating units revealed the possibility of a damaged glass dielectric. The suspected tube bundle was disassembled for inspection, which ultimately resulted in the replacement of a cracked tube. This gave plant personnel an excellent opportunity to examine the interior of the generator and learn the procedure for disassembly. The other start-up problems encountered involved minor electronic malfunctions.

Certain components of the ozonation system were not made of materials compatible with ozone. An example of this involved the use of reinforced neoprene sleeves supplied as flexible connectors at the inlets and outlets of the off-gas re-injection blowers. Although the supplier assured normal life expectancy of these components, the first sleeve failed after just four hours of continuous, stressed exposure. Replacement sleeves of silicon rubber have been in continuous service since then.

Plant personnel conducted an experiment in material selection that involved the installation of cast iron rotary blowers in the off-gas recirculation system, in lieu of stainless steel blowers. The stainless steel blower would have cost \$55,000, whereas a cast iron blower only cost \$11,000. Due to the price differential, it was decided that the use of cast iron blowers would be a worthwhile endeavor. These blowers have been in service for 15 months, with no evidence of attack by ozone.

The off-gas vent stack gave rise to two minor operational problems. An off-gas destruct unit was not supplied with the ozone system since ozone decomposer technology was in a state of development at that time, and installation of such equipment was delayed until new technology was proven. The first problem occurred when wind currents caused the off-gases from the vent stack to be drawn into the inlet of the building air-heating unit located on top of the ozone systems building. The heating-unit air inlet had been located too near the vent stack; thus, when the heating unit energized, it pulled ozone into the building which subsequently shut down the ozonation system via the ambient air-monitoring equipment located within the building.

The second problem occurred during very cold weather when moist off-gas from the contactor formed a crown of ice at the outlet of the vent stack. The ice formation grew until it completely blocked the passage of off-gases. This caused over-pressurization of the contact chamber, which forced the water level down until the low water level sensor triggered an automatic shutdown and broadcast the alarm condition. To alleviate the two aforementioned problems, plant personnel extended the height of the stack above the heating-unit air inlet, and also added heat tape and insulation to the vent gas stack.

According to plant personnel, the reliability of all equipment in the ozonation system has been outstanding. Since continuous operation of the ozonation equipment began, not one day of ozone application has been missed as a result of equipment failure. However, two incidents have occurred which resulted in the removal of one ozonator from service.

The first incident involved the failure of insulation on a "U"-shaped bracket used to support the silicon control rectifiers (SCR's) in the electronics cabinet of Ozonator Number 2. Although the installation of the new bracket was an easy matter, the ozonator was out of service for several days due to a delay in delivery of the replacement part.

The second failure occurred when tubing used to carry cooling oil to the heat sinks on the SCR slipped out of its fitting and caused a discharge of cooling oil onto the capacitor bank in the bottom of the electronics cabinet; from there it leaked onto the floor. The cooling oil, low-pressure interlock shut down the unit immediately and repairs were completed in a relatively short time, but clean-up of the spilled oil from the top of the capacitors was time consuming. The manufacturer was alerted to the problem, and a different tubing material was installed in order to prevent a recurrence. All materials and fittings to re-fit both ozonators were supplied by the manufacturer under warranty agreement.

The off-gas recompression blowers also suffered damage during the early months of operation. The first unit failed soon after it had been placed in operation because a piece of slag was left in the inlet during construction and was carried into the blower, causing it to seize. The second blower failure was caused by bearing failure as a result of in-plant modifications. The oil drains from both ends of the blower were connected and piped to a common valve to facilitate the draining of lubricant oil during maintenance. This arrangement allowed the timing gears, located in one end of the blower only, to act as a pump and draw

most of the oil from the opposite end through the newly-joined drain line, causing the bearing to fail for lack of lubrication. When the blowers were repaired, each was redesigned with an external lubrication system including a reservoir, filter, and heat exchanger, which ultimately prolonged the life of the lubricant oil and extended the period between oil changes. These modifications were performed by plant personnel. The blowers have subsequently had trouble-free operation.

There were several design changes made in the ozone system after analysis of the preliminary design. The first and possibly most significant change involved the collection and reinjection of the off-gases from the contactor into the first-stage contact unit. This was perhaps the most significant change that resulted in increased operating efficiency. Another design change involved redesigning the entire pressure control system for the contact chamber in order to provide additional safeguards for personnel and equipment during start-up, shut-down, and surge conditions.

During hydrostatic testing to ensure the gas-tight integrity of the contact vessel, several leaks were discovered in the floor slab separating the equipment from the contact chamber beneath it. It was discovered that the coatings applied to the free-boards surfaces within the contactor were not an ozone-resistant sealant, as specified, but a chlorinated rubber paint that was vulnerable to attack by ozone and had no sealing characteristics. Subsequently, all surfaces coated with the material had to be sandblasted, and a suitable ozone-resistant sealant found as a replacement. The material selected included a 1/8- to a 1/4-in. thick application of a one-part polyurethane elastomer over which a PTFE membrane was applied as a protection against ozone degradation. This system has thus far been 100 percent effective in sealing the chamber against ozone leaks.

Operations and Maintenance Staff

There were no significant problems encountered in training the personnel to operate the ozone system. There was sufficient opportunity for all employees to familiarize themselves with the physical aspects of the facility while it was under construction. Operations and maintenance personnel worked closely with the manufacturer's service representatives in preparing the system for start-up, gaining experience in dewatering, loading media into the regenerative dryer towers, and filling the insulating oil and lubricant oil systems. Operators also observed and assisted in all test procedures and were briefed by the five

manufacturer's start-up technicians. The ozonators were initially operated only during the day shift until all personnel were comfortable with the equipment and initial problems were corrected. Advanced instruction in such techniques as gas phase analysis and calibration procedures was given to only a few of the staff at first, but, as operators gained confidence, more were given this technical instruction in addition to regular in-plant training sessions. The operators now have a good understanding of the ozone system and are comfortable and confident in using it.

MAINTENANCE

Maintenance requirements for the ozone system are minimal according to the plant superintendent. A preventive maintenance program is followed as illustrated in Table 20. The particle filters and moisture traps are blown-down by the shift operator at the beginning of each shift. The operator regularly visits the ozonator room to check various instrument readings every shift. Any deviation from normal instrument readings is logged for immediate investigation by the maintenance staff. The maintenance staff performs routine lubrication and adjustment of mechanical components as required in the preventive maintenance program.

The most time-demanding maintenance involves keeping the building and equipment clean, which requires approximately four hours weekly. Routine mechanical maintenance has required as little as four man-hours monthly, exclusive of any breakdown. When personnel were familiarizing themselves with the equipment and developing maintenance techniques, this time requirement had been as high as 16 man-hours weekly. However, as the operators became more familiar with the equipment, maintenance time decreased. Currently, the ratio of operating hours to maintenance man-hours is approximately 30 hours of operation to 1 man-hour of maintenance.

As part of the facility maintenance program, the lead ozonator is taken out of service each month for filter cleaning and mechanical inspection. When the unit is returned to service, it becomes the lag machine or the "slave" unit, starting only when the lead unit cannot meet the ozone requirement alone. Lubricant oil is changed at six-month intervals in all blowers. The automatic ozone analyzer is checked at the beginning of each shift.

Diassembly and cleaning of internal parts is not necessary or recommended unless ozone production falls below 90 percent of

Table 20

<u>MAINTENANCE CHECK LIST</u>					
Item	D	W	M	M	Y
	l	l	l	h	l
	y	y	y	s	y
<u>Ozone Generators</u>					
Status of Indicator Lights	X				
Air Flow	X				
Air Pressure	X				
H.V. Coolant Oil Level	X				
Check on Sight Gauge at Reservoir					
Pressure at Discharge of H.V. Coolant Oil Pump	X				
Cooling Water Flow	X				
Cooling Water Temperature	X				
Clean Ozonator Cells					
					As Required
<u>Refrigeration Dryer</u>					
Evaporation Temperature Gauge	X				
Automatic Condensate Drain					
Flush and Blowdown			X		
Clean					X
<u>Desiccant Dryer</u>					
Dryer Status (Indicator Panel)	X				
Regenerative Column Temp.	X				
Purge Air Flow	X				
Drying Tower Pressure	X				
Desiccant					X
Check Change					
					As Required

Table 20
(continued)

<u>MAINTENANCE CHECK LIST</u>						
Item	D a i l y	W e e k l y	M o n t h l y	6	Y e a r l y	Other
				M o n t h s		
<u>Automatic Control Cabinet</u>						
Check Indicator Lights	X					
Compare Record and Control- ler Reading	X					
Calibration Check on Residual Ozone Analyzer	X					
<u>Room Ozone Detector</u>						
Check Air and Ethychem Flows	X					
Change Inlet Air Filter			X			
Change ETHYCHEM Filter						
Replace Desiccant Cartridge					X	3 Months As Required
<u>Particle Filter</u>						
Blowdown	X					
Clean			X			
<u>Blower</u>						
Check Oil Level	X					
Change Oil and Filter					X	
Belts (Tension)			X			
Clean Oil Breather					X	
<u>Blower Motor</u>						
Lubrication						As Required

Table 20
(continued)

<u>MAINTENANCE CHECK LIST</u>					
Item	D	W	M	M	Y
	a	e	o	o	e
	i	k	n	n	a
	l	l	h	t	r
	y	y	y	s	y
<u>Auxiliary Compressor</u>					
Check Pressure Gauge	X				
Drain Tank		X			
Change Filter Felt					As Required
<u>Dew Point Hygrometer</u>					
Check Dew Point	X				
Check Air & Water Flow	X				
Clean Mirror & Sensor					As Required

rated capacity with a dew point of -40°F or higher. As long as air preparation equipment functions normally and only clean, dried air is admitted to the ozonators, production remains constant.

OPERATION AND MAINTENANCE COSTS

The capital investment for the Monroe Ozonation System was \$711,800. A breakdown is shown in Table 21. One third of the total amount (\$235,000) was for yard piping and valves necessary to transfer raw or settled water from the primary clarifier to the contact chamber, and to carry ozonated water from the contactor to either the clarifiers or to the filters. These features were incorporated into the plant design to increase the operating flexibility.

The ozone generator, instrumentation, and distribution and off-gas recycling equipment are scheduled for amortization over 20 years. The substructure and superstructure (building) are scheduled for amortization over 50 years, and the underground piping and valves for 100 years.

The major cost of operating ozone equipment is for purchased electric energy. Electricity, which is required for building lighting, pumping, monitors, and other ancillary equipment, is insignificant compared to the power requirements of the ozonators and their auxiliaries (see Table 22).

Net power consumption for ozone generation, gas preparation, and off-gas recompression varies inversely with the amount of ozone produced by each ozonator. The increase in power actually used to produce ozone in the cells is nearly linear from 3.47 kwh-lb at 20 percent of rated capacity to 6.40 kwh-lb at full output of 125 lb per day.

The power consumption of all ancillary equipment, which includes feed gas conditioning and recompression of off-gas, is constant at 872 kwh-day, regardless of the output of the ozonator. Thus, at 20 percent of the capacity of one ozonator, the total power requirement is 17.95 kwh-lb, while at 100 percent output the power requirement drops to 10.28 kwh-lb. It is, therefore, more economical to operate only one ozonator (if it will handle the demand) than to run two ozonators in parallel at less than 50 percent of each unit's capacity. It also aids mass transfer of the ozone to operate at the higher ozone concentrations that are produced when an ozonator is operated near design capacity.

System operation and maintenance costs are presented in Table 23.

Table 21

Capital Investment: Monroe Ozonation System

Expenditure	Amount \$
Earthwork	5,800
Bearing Caissons	26,000
Reinforced Concrete Tank and Superstructure Housing	39,000
Ozone Equipment and Instrumentation	270,000
Ozone Distribution and Recycling Equipment	25,000
Piping and Valves	235,000
TOTAL	711,800

Table 22
Power Consumption and Operating Costs of Ozone Plant*

Percent of Total Output Capacity	Output per Hour at Level Shown in First Column kg/h	Output per Hour lb/h	Corona		All Auxiliaries (Air Prep., etc.) kwh/kg	Total Ozonator		Reinjection System		Total Power kwh/kg	Total Power kwh/lb	Power Cost \$/kg	Power Cost \$/lb	
			Cells Only kwh/kg	Cells Only kwh/lb		Auxiliaries kwh/kg	Auxiliaries kwh/lb	Off-gas kwh/kg	Off-gas kwh/lb					
10	0.72	1.58	7.63	3.47	29.25	13.33	36.88	16.80	21.99	9.66	58.87	26.46	2.27	1.02
20	1.19	2.63	9.08	4.11	17.70	8.01	26.78	12.12	12.82	5.80	39.60	17.92	1.53	0.59
30	1.66	3.67	10.60	4.80	12.69	5.74	23.29	10.54	9.19	4.16	32.48	14.70	1.25	0.57
40	2.12	4.67	11.13	5.06	9.93	4.51	21.06	9.57	7.20	3.27	28.26	12.84	1.09	0.50
50	2.57	5.67	11.52	5.22	8.19	3.71	19.71	8.93	5.94	2.69	25.65	11.62	0.99	0.45
60	2.97	6.54	12.05	5.47	7.09	3.22	18.14	8.69	5.14	2.33	24.28	11.02	0.94	0.43
70	3.34	7.38	12.49	5.65	6.31	2.95	18.80	8.50	4.57	2.07	23.37	10.57	0.90	0.41
80	3.68	8.13	12.93	5.86	5.72	2.59	18.65	8.45	4.15	1.88	22.80	10.33	0.88	0.40
90	3.99	8.79	13.51	6.13	5.28	2.40	18.79	8.53	3.82	1.74	22.61	10.27	0.87	0.40
100	4.23	9.33	14.11	6.40	4.98	2.28	19.09	8.56	3.61	1.64	22.70	10.30	0.87	0.40

*All data are based on actual power measurements; power costs are computed on unit cost of \$0.0386/kwh.

Table 23

Monroe Water Treatment Plant
Ozone System Cost Sheet

O₃ Generation Rate = 35.5 kg/d at 2 mg/L
FCI = \$711,800

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power			
Compression	14.6	4.4	64
Recompression	10.25	4.4	45
Generation	9.99	4.4	44
	Mgal/kg	¢/Mgal	
Cooling Water	0.47	5	2
Operating Labor (1/2 hr./shift)			61
Repair Labor (includes P.M.)			34
Supervision (15%) (O.L. + R.L.)*			14
Repair Materials (1% FCI)*			55
Supplies (10%) (O.L. + R.L. + Supv.)*			<u>11</u>
Total Operating Cost			330
<u>Overhead Cost</u>			
Insurance (1% FCI)*			55
Amortization (7% at 20 years)			<u>518</u>
Total Overhead Cost			573
TOTAL OZONE COST ¢/kg (¢/lb)			903 (408)

FCI, Fixed Capital Investment
O.L., Operating Labor
R.L., Repair Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

BAY METRO WATER TREATMENT PLANT
BAY CITY, MICHIGAN

GENERAL

Bay City, Michigan is located in the northeastern portion of the state, approximately 100 miles northwest of Detroit on Interstate Route 75 (see Figure 37). Bay City lies on the western shore of Lake Huron and draws its water from the Saginaw Bay, an arm of Lake Huron. The City's 4-1/2-mile long water intake runs approximately 2 miles into the south end of the bay and lies 18 to 25 ft below the water surface, depending on the time of year and bay level.

The Bay Metro facility was originally constructed in 1921. By the mid 1970's the City was faced with either renovating and expanding its water treatment facility, or constructing a new one in order to meet the growing water supply needs of the Bay City area. A study of these two alternatives indicated that it would be more cost-effective to construct a new facility. The new plant, which went into operation in September of 1979, is a 40 mgd lime-soda ash softening, water filtration facility. The present average daily flow is 10.0 mgd, and the present maximum daily flow is 16.0 mgd. The plant was visited on 18 March 1982.

The main treatment steps utilized include: screening for removal of floatable materials; taste and odor control, utilizing ozone; lime-soda ash softening; primary and secondary clarification; dual media filtration; disinfection; and fluoridation. The plant process flow diagram is shown in Figure 38.

The plant's source of raw water presented a significant problem in the design of the facility. Saginaw Bay is large and relatively shallow, and receives considerable surface runoff from a variety of land uses ranging from intensive urban development to agriculture. Because of the shallow depth and changing wind currents, the water quality changes very rapidly; this had resulted in frequent taste and odor problems, particularly in spring, summer, and early fall. The new treatment system uses ozone by itself or in combination with activated carbon for taste and odor control. To date, activated carbon addition has not been required. While ozonation has been previously used in Europe and Canada for water treatment, Bay Metro is one of the first plants in the United States to use such a system. It is also the largest water plant in the United States with a surface water supply that uses ozonation.

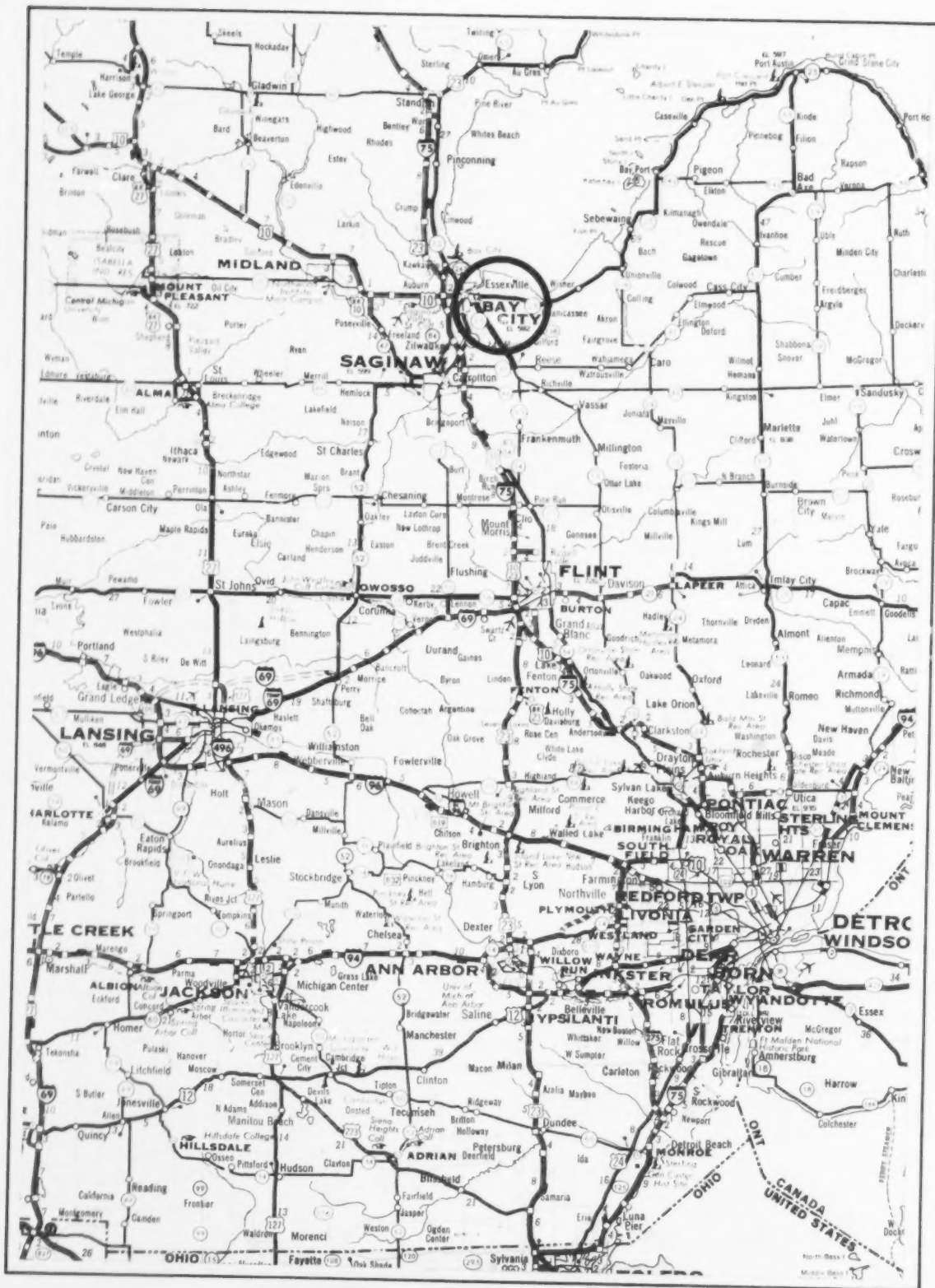


FIGURE 37 PLANT LOCATION MAP

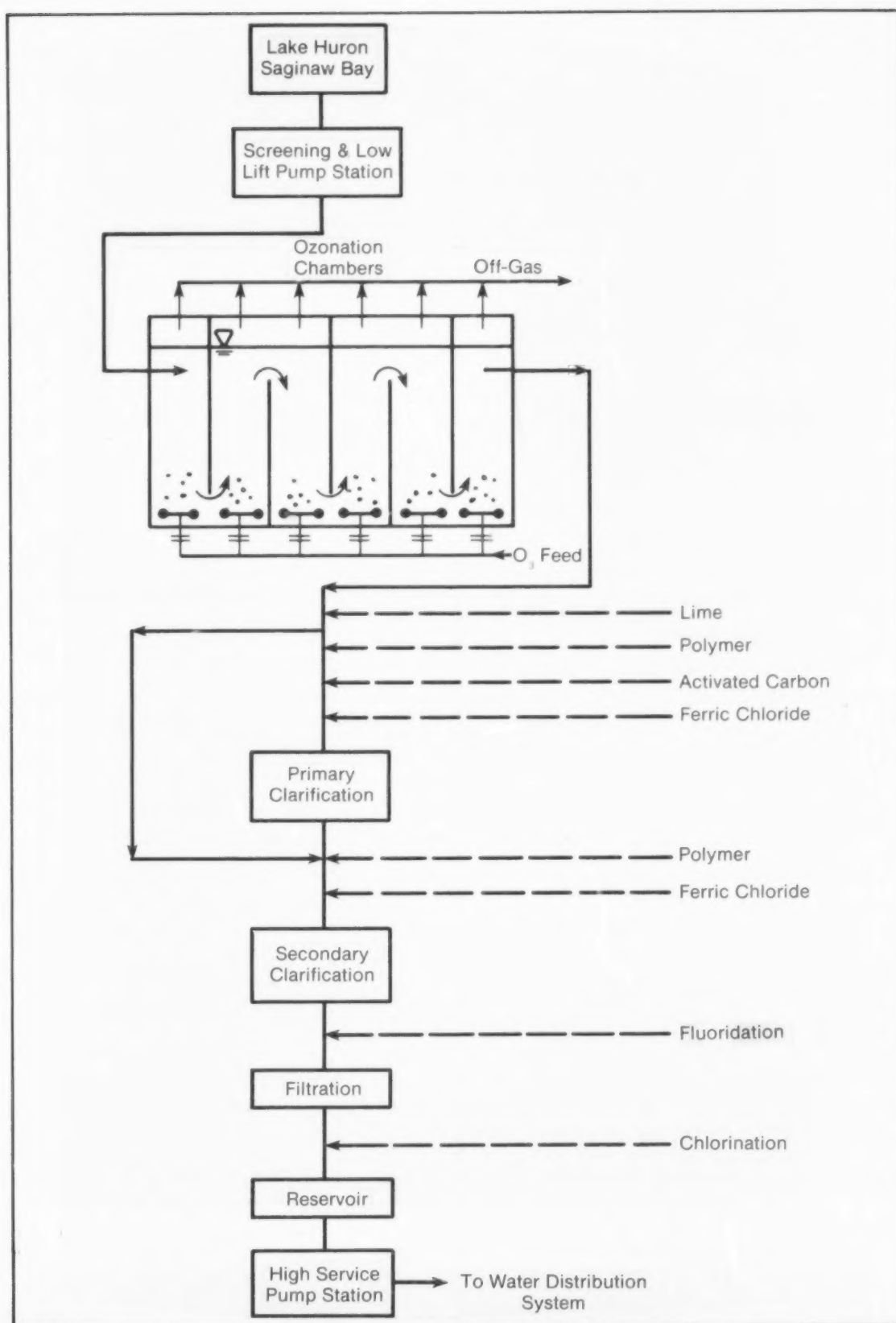


FIGURE 38 PLANT PROCESS FLOW DIAGRAM

The primary use for ozonation at the plant is odor and taste reduction; however, various supplementary benefits of ozonation are also realized along with the destruction of odor and taste. These include disinfection, destabilization of certain colloids, enhanced flocculation, better settling, and reductions in chlorine demand. In addition, the use of ozone prior to chlorination results in oxidation of humic materials, which are precursors to trihalomethanes. Thus, the ozonation process minimizes the generation of trihalomethanes.

Two digital, micro processor controllers at the plant are used for process monitoring, data gathering, report generation, and automatic control functions. Both systems have a 64K memory and share the same CRT and high speed printer. Accumulated data is transmitted hourly to a TRS-80 Model II micro processor for data processing, storage, and analysis. One of the units performs the process chemistry-related functions, including: chemical feed control (lime, soda ash, polyphosphate, alum, sulfuric acid, carbon slurry); chlorination control; ozonation control; and control of sampling system. In addition, it monitors and accumulates data on all the plant chemical parameters (hardness, alkalinity, pH, turbidity, etc.), and prepares hourly and daily typed reports and operating records using the above data.

A second micro processor is provided to perform data gathering, reporting, data transfer, and automatic control functions for the plant process hydraulics, including: control and monitoring of low lift pumping; control of flow proportioning between clarifiers; filter on-stream/off-stream assignment; filter rate of flow determination; control and monitoring of waste washwater flow; control and monitoring of high service pumping; control and monitoring of plant electrical demand; monitoring and accumulating data on all plant hydraulic parameters (i.e., levels, pressures, flows, etc); and preparation of hourly and daily typed reports and operating records using the above data.

OZONE SYSTEM DESCRIPTION

Ozone at Bay Metro is generated by four Welsbach Ozone Systems Corp. Model H-204 ozone generators, each rated at 250 lb/day production capacity. Each of the generators has two tube bundles that contain 102 water-cooled dielectric tubes per tube bundle (204 total per generator). The generators can be operated alone or in combination, as the demand requires.

The ozonation system consists of four basic components, including air preparation, electrical power supply, ozone generator, and ozone contactor. A simplified schematic of the Bay Metro ozonation system is shown in Figure 39. Air preparation includes initial refrigerant air cooling and desiccant drying to a minimum dew point of -40°C . This air is then passed through a high-voltage field created between two dielectrics where the ionized portion of the oxygen combines with the nonionized oxygen molecules to produce ozone. The ozone gas is then mixed with the raw water in a contact chamber for a total contact time of 30 minutes. Each generator is a complete system, including air preparation and drying, power supply, control equipment, and a two bundle housing mounted on skids.

A PCI Ozone Corporation Model HC-12 ozone analyzer is mounted on the wall of the generator room and measures and displays the percent of ozone in the discharge from the ozone generator. The probes for this analyzer are located in the ozone feed lines to the contact chamber.

A Welsbach Model 724-2 meter, also mounted in the generator room, continuously monitors the room air for ozone leaks and, if any are detected, sounds an alarm and automatically shuts down the generators. A similar meter is located in the center of the primary clarifier bay to monitor the ozone content of the ambient air.

Both of Bay Metro's contacting chambers are 105 ft long, 29 ft wide, and 15 ft deep, with a water depth of 14 ft (see Figure 40). The chambers are divided length-wise by a common center wall that separates them into contacting and detention basins. The contacting side of each chamber is further divided into four bays by over-and-under baffles. Each bay contains 16 porous-tube, bubble-type diffusers, providing a total of 64 diffusers in the contacting side of each chamber. Both contacting chambers are once-through units; there is no recirculation of ozone containing air or any pressurization of the chamber.

The operating parameters for the ozone unit are as follows:

- Ozone Output -- 25 to 250 lb/day.
- Ozone Capacity -- 250 lb/day at 1 percent (weight) concentration.
- Air Flow -- 170 scfm.

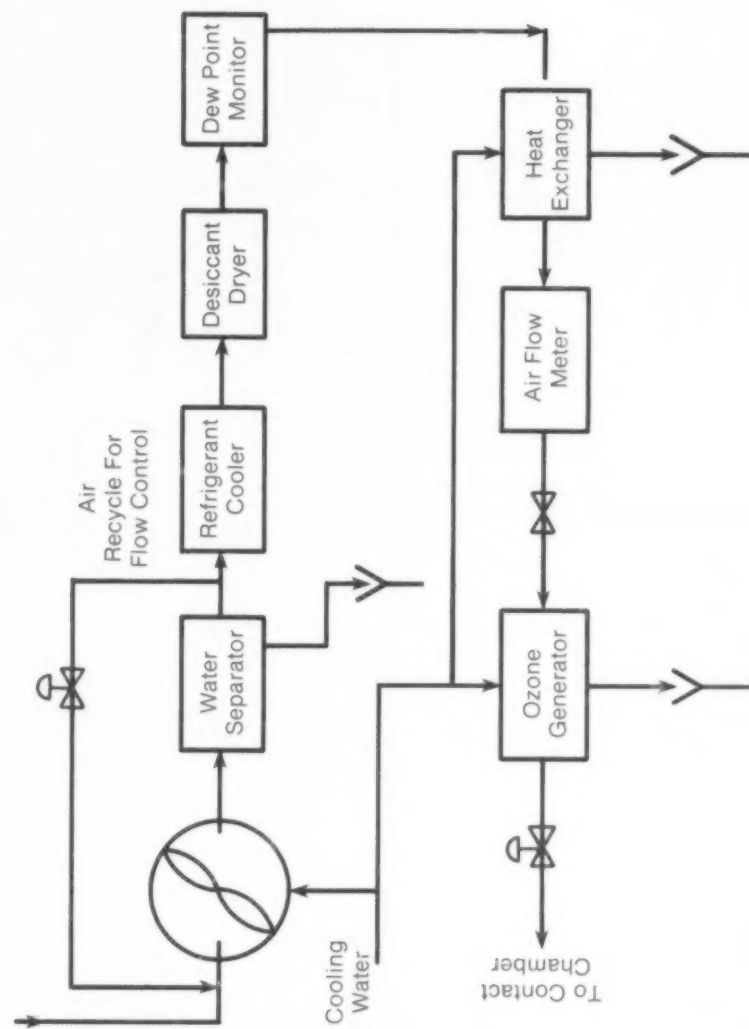


FIGURE 39 OZONE SYSTEM FLOW SCHEMATIC

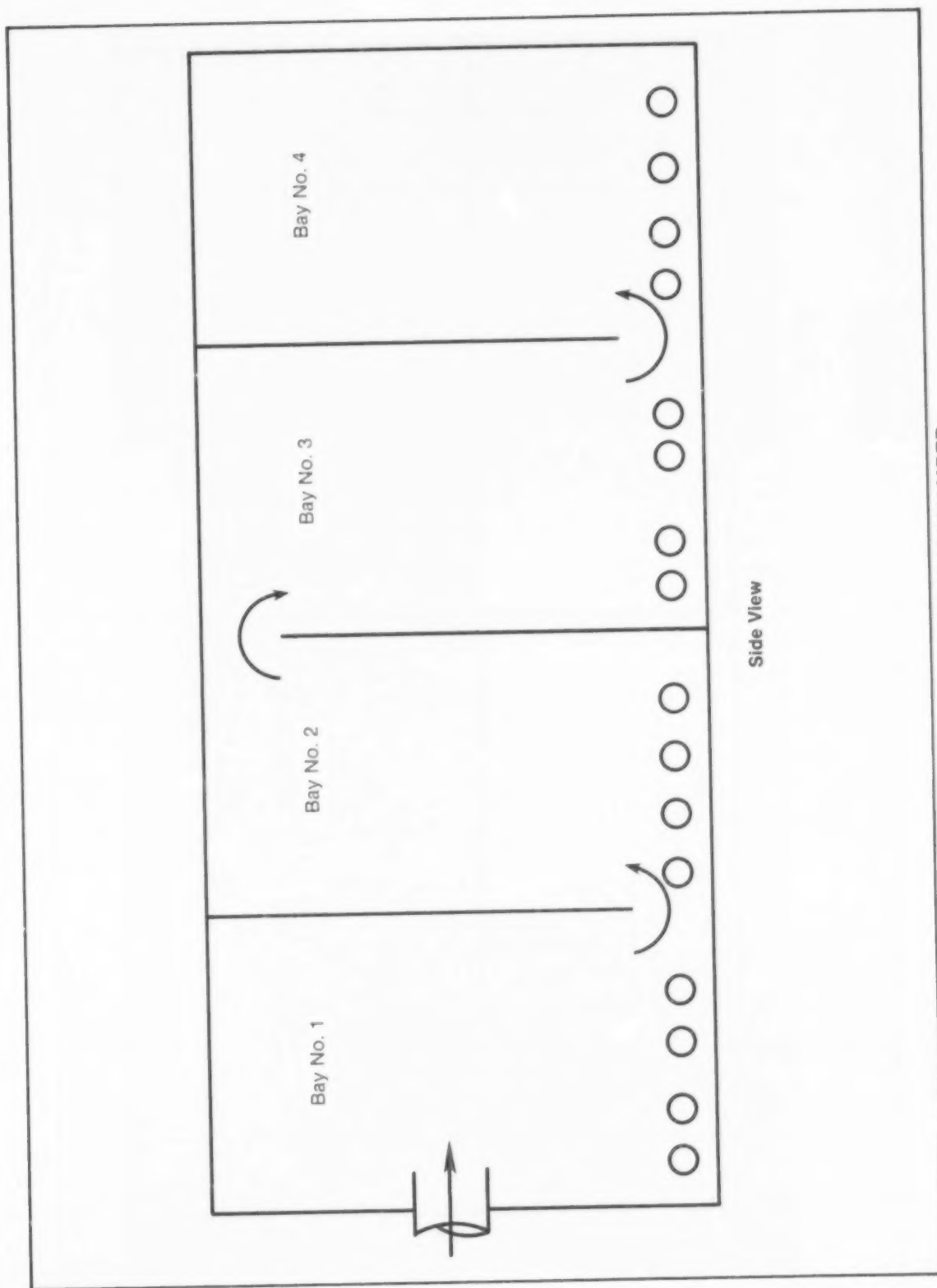


FIGURE 40 OZONE CONTACT CHAMBER

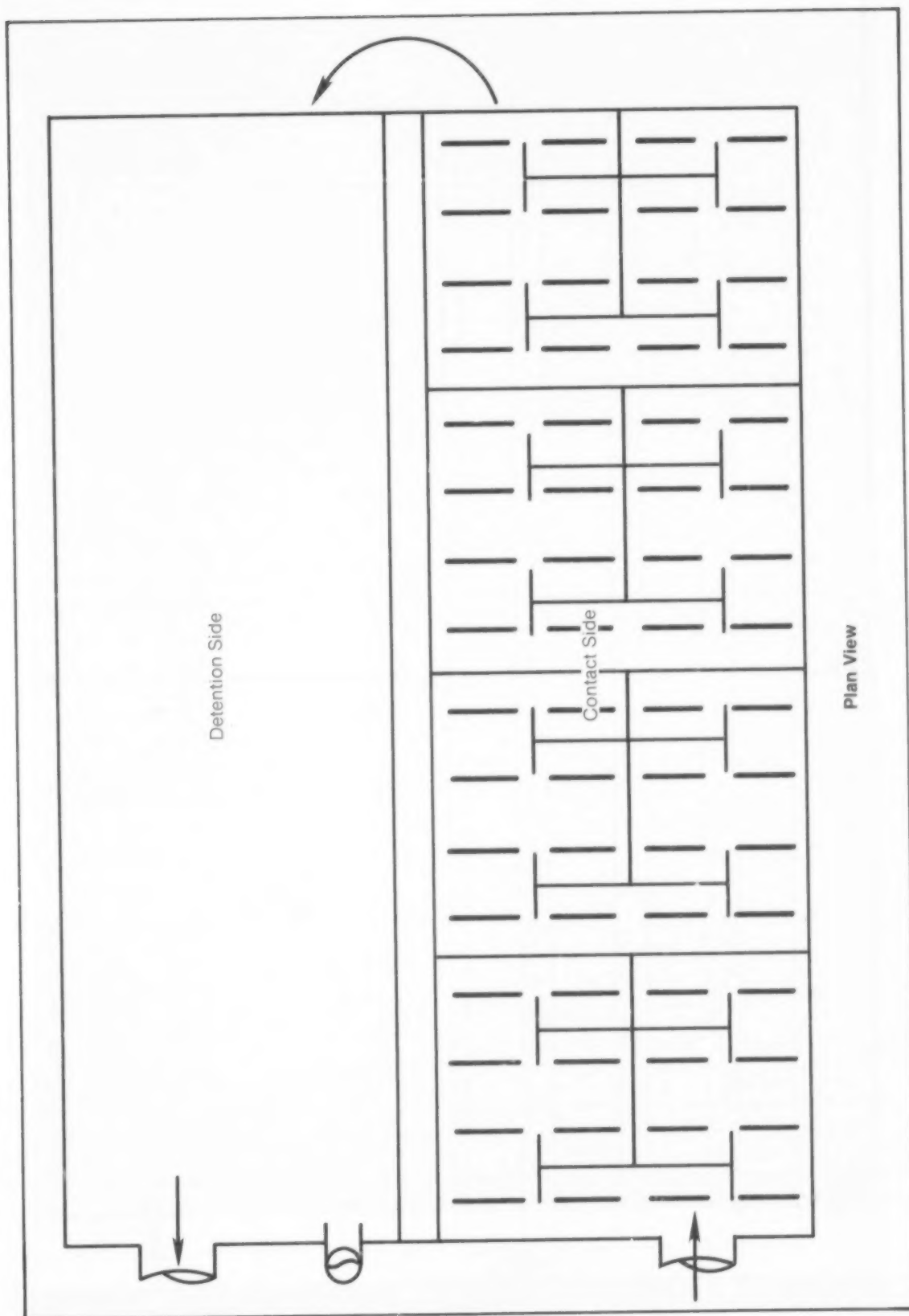


FIGURE 40 (Continued)

- Dew Point -- minus 40°F or lower.
- Cooling Water -- 43 gpm, maximum temperature 70°F.
- Ambient Temperature -- 40 to 100°F.
- Ozone Output Control -- local or automatic (micro processor controlled).

The ozonation system air compressor is a Nash Model L-4, which is a centrifugal, one-stage, water-sealed blower with a 30-hp motor. It will deliver 230 scfm of air at a discharge pressure of 12 psig. The air feed to the blower is prefiltered to remove particulate matter and moisture. A water separator is installed after the compressor to remove any excess water which may be contained in the air. A refrigerant dryer is used to reduce the dew point of the air leaving the compressor to approximately -40°F. Pre-cooling of the inlet air stream and reheating of the outlet air stream is accomplished by a heat exchanger. The refrigerant dryer is supplied with a 4-hp motor. Air flows from the refrigerant dryer to a regenerative-type dryer that uses molecular sieves and activated alumina to further reduce the dew point to below -40°F. The desiccant dryer can deliver 230 scfm of air at a dew point of -40°F or lower. The dryer consists of two towers which contain 200 lb of alumina. The dryer operates on an 8-hour cycle; one tower dries the air during the entire 8-hour cycle, while the other tower regenerates. To regenerate the dryer, an electrode heater, which is controlled by a thermostat, heats the dryer contents to a temperature between 200°F and 260°F. The tower is heated for a maximum of four hours and is then cooled for a minimum of four hours. After eight hours, an auxiliary compressor activates a pneumatic valve which causes the dryer towers to switch, thus restarting the 8-hour cycle on the opposite tower. The dryer operation is fully automatic. An in-line filter prevents carry-over of desiccant fines to the ozone-generating cells. A water-cooled heat exchanger is located after the in-line filter and is used only if the air temperature exceeds 38°C.

The ozone generator is a Welsbach Model GLP 204-F206 that will continuously supply a maximum of 250 lb of 1 percent (by weight) ozone per 24 hours. Each unit contains 204 horizontal, water-cooled, dielectrics. The glass dielectrics are surrounded by a stainless steel tube. Dry air, which is converted to ozone, flows through the air gap between the stainless steel and glass electrodes. Cooling water flows around the outside of the stainless steel tube to cool the cell. Cooling water requirements are

approximately 50 gpm per generator. The power supply to the ozone generator system is a 60-Hz fixed frequency, variable voltage system. The voltage to the dielectrics can be controlled from the generator control panel.

The ozone contact chamber is located adjacent to the ozone systems room and employs a co-current/counter-current gas diffuser system. Ozone-rich air, at a concentration of 1 percent (by weight) in air, is fed into the diffusers through three-in. stainless steel piping, with the ozone flow being evenly divided between all four bays of the chamber-contacting side. Detention time in the contacting side of the ozonation chambers is 40 minutes at 12 mgd flow and 17 minutes at 20 mgd flow. After the water passes through all four contacting bays, it then flows into the detention basin side to allow the ozone to oxidize the foul taste and odor causing materials, and to disinfect the raw water. Each ozone contacting chamber is also equipped with a residual ozone analyzer. The analyzer probes are installed at the halfway point in the detention side of each of the two ozone contacting chambers. The signals from these analyzers is transmitted by a 4-20 ma signal to the plant's micro processor which, in turn, adjusts the ozone generator's output to maintain the desired ozone residual at this monitoring point.

The current method of analyzing ozone is via on-line UV photometers incorporated in the PCI Ozone Corporation ozone analyzer mounted on the wall of the generator room. During the plant visit, the meter was indicating a 0.91 percent (by weight) ozone concentration at an air flow of 182 scfm. The ozone gas feed stream was sampled to determine the concentration of ozone utilizing the neutral potassium iodide (KI) method. The carrier gas stream contained 9.9 mg/L of ozone (.82 percent by weight). At the current flow of 10 mgd, this translates to an ozone dosage of 3.3 mg/L.

The off-gas from the north ozone contact chamber was sampled and the ozone concentration determined by the KI method. The ozone concentration of the off-gas was determined to be 1.46 mg/L, which indicates an ozone transfer efficiency of 84.8 percent.

Additional instruments associated with the ozone equipment include the following:

- Dew Point Meter - A dew point meter measures the absolute humidity of the air to the ozonator cells. This was recently installed by plant personnel.

- Air Flow Meter - A flow meter measures the air flow rate to the ozonator cells.
- Voltage Indicator/Regulator - A voltage meter indicates the AC voltage to the step-up transformers, which is proportional to the ozone output of the unit.

Off-gas from each of the contacting chambers is vented through PVC piping into the atmosphere, 72 ft above the plant. No ozone destruct unit is installed on either of the exhaust stacks at the present time.

FACILITY OPERATIONS

Ozone System Control

An ozone dosage of 0.5 to 2.5 mg/L depending on the oxidant demand of the raw water, is used. Currently, the ozonation system feed rate is manually controlled. One ozone generating unit is on-line all the time, although the ozonation system was designed for intermittent use as dictated by raw water quality. However, there are provisions for residual monitoring during manual operation. The residual ozone meter probes are located halfway down the length of the ozone contact chamber on the detention basin side and monitor the dissolved ozone concentration in the water. The signal from the analyzer may be used by the micro processor to fine-tune the ozone generator's output to maintain the desired residual. In the automatic mode, the generators can be operated alone or in combination, as the demand requires.

Start-up and normal shut-down of the Welsbach generators is controlled from the generator room by a plant operator. Fine adjustment of the ozone output is controlled by the micro processor located in the plant control room.

Start-Up and Operational Problems

One of the initial problems encountered with the ozone system involved the high-voltage electrical system supplied with the units. The system was initially designed for 23,000 volts; however, this was reduced to 18,000 volts due to "burn-out" problems with the glass dielectrics. The manufacturer redesigned the current flow scheme and removed the transformers from the system to control the current to the generator in order to keep the system more stable. Problems were also experienced with the power stat, which varied the voltage during start-up from 480 to

350 volts. However, this problem was corrected by the manufacturer.

Initially, Bay Metro had considerable problems with dielectric tubes; this has been attributed to several causes. The manufacturer recommended a dew point of -40°C ; however, there was no way to control the dew point and no dew point meter was supplied with the original equipment. Thus, it was theorized that the initial dielectric failures were due to moist air entering the generator cell. To compound this, it was discovered that the wrong type of freon was initially used in the refrigerator cooler. In addition, the manufacturer has changed the type of desiccant in the dryer towers to achieve a lower dew point of less than -40°C . The original desiccant was 400 lb of H-151-activated alumina over a base of 300 lb of T-1061 aluminum balls. The new media configuration consists of a base of 200 lb of aluminum balls, 100 lb of 4A molecular sieve, and 300 lb of H-151-activated alumina. This is also believed to aid in increased ozone production due to a more stable dew point. Plant personnel now perform a manual dew point determination on the carrier gas to the generator once per shift to ensure that an acceptable dew point is maintained.

As part of the preventive maintenance program, the glass dielectrics were initially cleaned with soapy water and air dried. This method was believed to leave dirt on the dielectrics, and the dirt on the tubes tended to heat up and burn through the glass. The cleaning method was changed to incorporate a final alcohol rinse, and the operators now wear gloves to prevent smudges on the glass.

An additional problem was encountered when the heating electrodes in one of the desiccant drying towers burned out. When the unit was shut down for maintenance, it was discovered that 9 of the 18 electrodes had failed. The manufacturer attributed this to an improper desiccant level in the tower and excessive moisture in the gas stream. Currently, the only way to check the operation of the electrodes is by monitoring the temperature inside the tower during normal operation of the equipment. Thus, if the electrodes were to fail during operation, there would be a possibility of moist air flowing to the generator which would affect ozone production. This problem has not been resolved to date. Maintenance on the drying towers has been hampered by the placement of the electrical conduits directly over the desiccant chamber. To replace or inspect the electrodes, the entire unit must be disassembled and removed from the skid.

An additional problem with the air drying tower involves the pneumatic cylinders, for they would periodically "hang up" and therefore not switch tower operation, thereby allowing moist air to enter the ozone-generating cell. The pneumatic cylinders require periodic rebuilding to prevent this from reoccurring.

The fuses associated with the dielectrics, which were designed to protect the dielectrics from overcurrent, used to burn out; however, electricity still flowed through the fuses to the dielectrics. The manufacturer is now working on a new design that has the element attached to the outside of the fuse body and is encased in plastic. If the element burns, it drops away from the fuse body, thus stopping the flow of electricity to the dielectric.

Due to the frequent pitting of the dielectric tubes and arcing across the glass dielectric to the stainless steel sheath, some of the stainless steel tubes inside the generators had to be replaced. However, due to space restrictions, replacement of stainless steel tube requires the removal of the generator cover from the opposite unit.

Current operating problems with the ozone generators are minimal since the electrical modifications have been made by the manufacturer. The problems with the dielectrics also seem to have been mitigated since the manufacturer recommended the replacement of the desiccant with partial substitution of a 4A molecular sieve to obtain lower dew points.

The system is currently operated in the manual mode for various reasons. As previously noted, the residual ozone meter probes were located halfway along the length of the contact basin detention chamber to monitor the dissolved (i.e., residual) ozone concentration in the water. The contact time, at this point, is in excess of 45 minutes at current flows, making it very difficult to monitor ozone residual since ozone is very unstable in solution. The sample point for the residual ozone meter has since been changed to the inlets of the detention chamber. In addition, the Fisher and Porter residual O_3 analyzer is located in the primary clarifier room due to its proximity to the ozone contact chamber. The prefilter device on the analyzer frequently plugs due to the particulate material contained in the raw water. Thus, when the prefilter plugs, the residual analyzer does not receive a sample and this ultimately affects micro processor control. Facility personnel are currently investigating a means of automatically cleaning this prefilter.

OPERATIONS AND MAINTENANCE STAFF

Operator motivation and interest in the ozone system was excellent during the plant visit. The problems encountered during start-up provided the plant staff with good learning opportunities.

Bay Metro has a laboratory for continuous monitoring of water quality throughout all stages of the treatment process. The facility also has a separate laboratory for investigating taste and odor problems.

MAINTENANCE

A routine preventive maintenance schedule has been implemented at the Bay Metro facility. The preventive maintenance program is listed in the facility's O&M manual. A complete spare parts inventory for the ozone system has not been compiled due to the availability of spare parts from the other generators. Although there are four generators, only one is in use at any one time due to the current low flows. The current spare parts inventory consists mainly of electrical components (solenoids, relays, etc.), pneumatic cylinder (piston) rebuilding kits, fuses, desiccant, and dielectrics.

OPERATIONS AND MAINTENANCE COSTS

Power consumption is approximately 9.03 kwh/lb (18.9 kwh/kg), based on a single generator in operation. At Bay Metro's power cost of 4.2¢/kwh, this is equivalent to 37.92¢/lb (79.4¢/kg) at an application of 2.33 mg/L and a 10 mgd flow. The operation and maintenance costs associated with the Welsbach generators are tabulated in Table 24. All the computations are based on operating one ozone generator at the current maximum output of 195 lb/day (88.5 kg/day).

Field tests conducted during the plant visit indicated a maximum output of 214 lb/day (97 kg/day). These computations are presented in Table 25. Based on operating one ozone generator at the measured maximum output of 214 lb/day (97 kg/d), this is equivalent to a power consumption of 8.22 kwh/lb (18.2 kwh/kg). At Bay Metro's power cost of 4.2¢/kwh, this is equivalent to 34.52¢/lb (76.4¢/kg) at an application of 2.56 mg/L and a 10 mgd flow.

Table 24

Bay Metro Water Treatment Plant
Ozone System Cost Sheet

O₃ Generation Rate = 85.5 kg/d at 9.64 mg/L
FCI = \$1,250,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power			
Air preparation	6.1	4.2	26
Generation	13.78	4.2	58
	Mgal/kg	¢/Mgal	
Cooling Water	0.7	6.3	4
Operating Labor (.175 MY)			17
Repair Labor (.228 MY)			22
Supervision (0.046 MY)			4
Repair Materials (1% FCI)*			39
Supplies [10% (O.L. + R.L. + Supv.)]*			4
Total Operating Cost			174
<u>Overhead Cost</u>			
Insurance (1% FCI)*			39
Amortization (7% at 20 years)			378
Total Overhead Cost			417
TOTAL OZONE COST ¢/kg (¢/lb)			591 (267)

MY, Man year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor
R.L., Repair Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

Table 25

Bay Metro Water Treatment Plant
Ozone System Cost Sheet

O₃ Generation Rate = 97 kg/d at 9.9 mg/L
FCI = \$1,250,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power			
Air preparation	5.58	4.2	23
Generation	12.58	4.2	53
	Mgal/kg	¢/Mgal	
Cooling Water	0.64	6.3	4
Operating Labor (.175 MY)			15
Repair Labor (.228 MY)			20
Supervision (0.046 MY)			4
Repair Materials (1% FCI)*			35
Supplies [10% (O.L. + R.L. + Supv.)]*			<u>4</u>
Total Operating Cost			158
<u>Overhead Cost</u>			
Insurance (1% FCI)*			39
Amortization (7% at 20 years)			<u>378</u>
Total Overhead Cost			417
TOTAL OZONE COST ¢/kg (¢/lb)			575 (261)

MY, Man year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor
R.L., Repair Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

CHARLES J. DES BAILLETS WATER FILTRATION PLANT
CITY OF LA SALLE, CANADA

GENERAL

The Charles J. Des Baillets Water Filtration Plant is located approximately 15 miles southwest of Montreal (see Figure 41). Construction of the plant began in 1973 and was completed in 1978 at a cost of 185 million dollars. The plant's average treatment capacity is 300 mgd, with a temporary peak overload capacity of 375 mgd. A site visit was conducted on 15 April 1982.

The Charles J. Des Baillets plant currently treats an average flow of 211 mgd. The plant's treatment scheme incorporates raw water screening and pumping, filtration, ozonation for disinfection and taste and odor control, and chlorination to maintain a residual disinfectant concentration in the distribution system. A plant flow diagram is shown in Figure 42.

OZONE SYSTEM DESCRIPTION

Ozone is produced by six Trailigaz horizontal-tube, water-cooled ozonators. Each generator contains 558 dielectrics and is rated at 1,280 lb of ozone per day at a maximum concentration of 1.17 percent. Three ozone generators are currently required to meet the plant's ozone demand of 2.2 mg/L. Ozone (1 to 2 percent by weight) is fed into 6 contact chambers. Each contact chamber is 131 ft long, 20 ft wide, and 26 ft deep, which provides a 5-minute detention time at the design flow rate of 300 mgd. Ozone is discharged into the contact chamber through a series of ceramic diffusers.

Each contact chamber is divided into four compartments, as illustrated in Figure 43. There are two stainless steel pipes that feed ozone to the second compartment of the contactor, and one stainless steel ozone feed pipe to each of the other two contact compartments. There are 63 ceramic diffusers installed in compartment No. 2, 22 diffusers in compartment No. 3, and 22 diffusers in compartment No. 4. Residual ozone monitors are installed in each compartment of the contact chamber; however, only the third stage residual is used for computer control of the ozonation process. Pilot tests conducted during the early stages of design indicated that a dosage of 1 mg/L would be required to achieve a residual ozone concentration of 0.4 mg/L after 5 minutes of detention time.

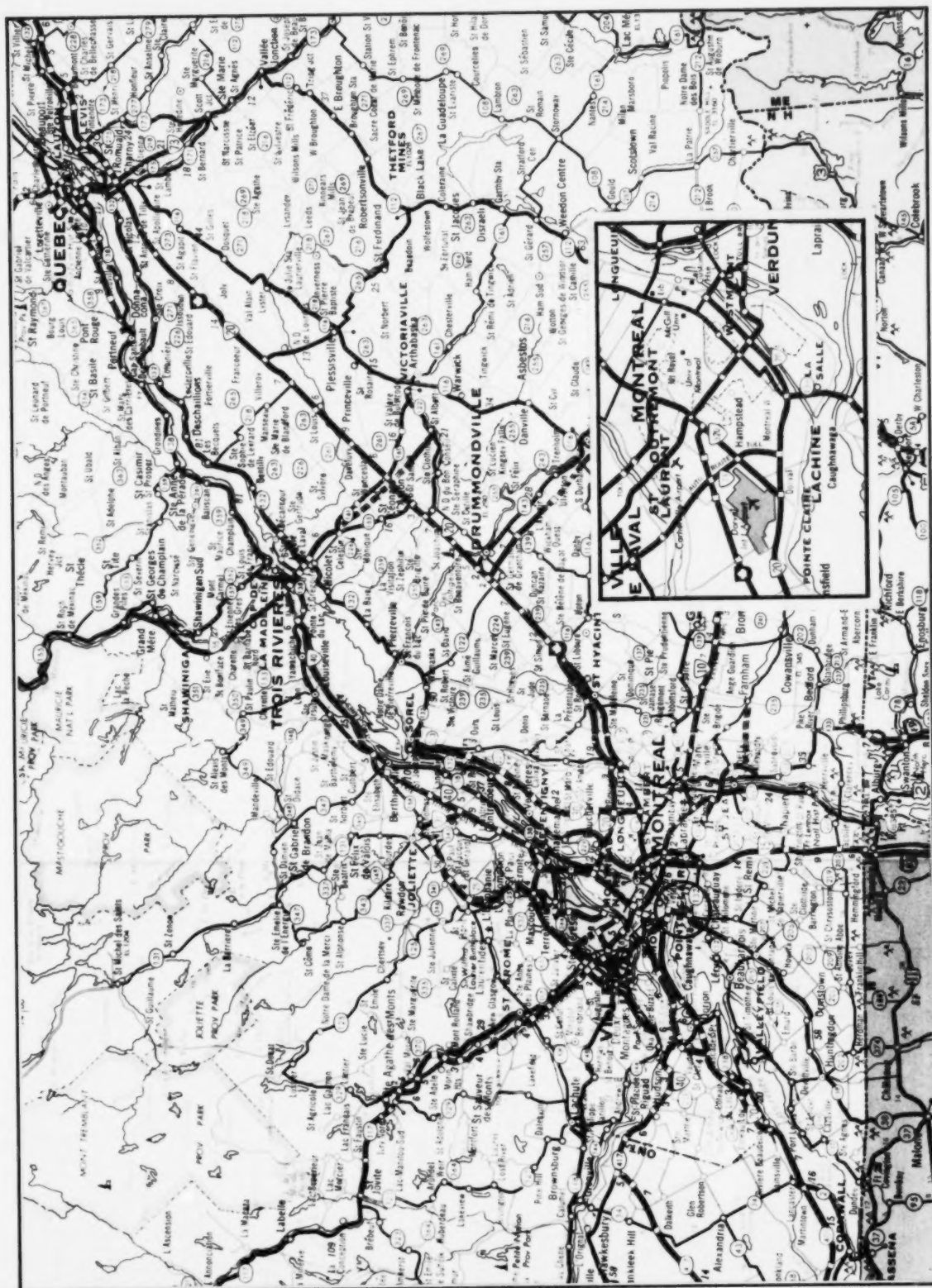


FIGURE 41 PLANT LOCATION MAP

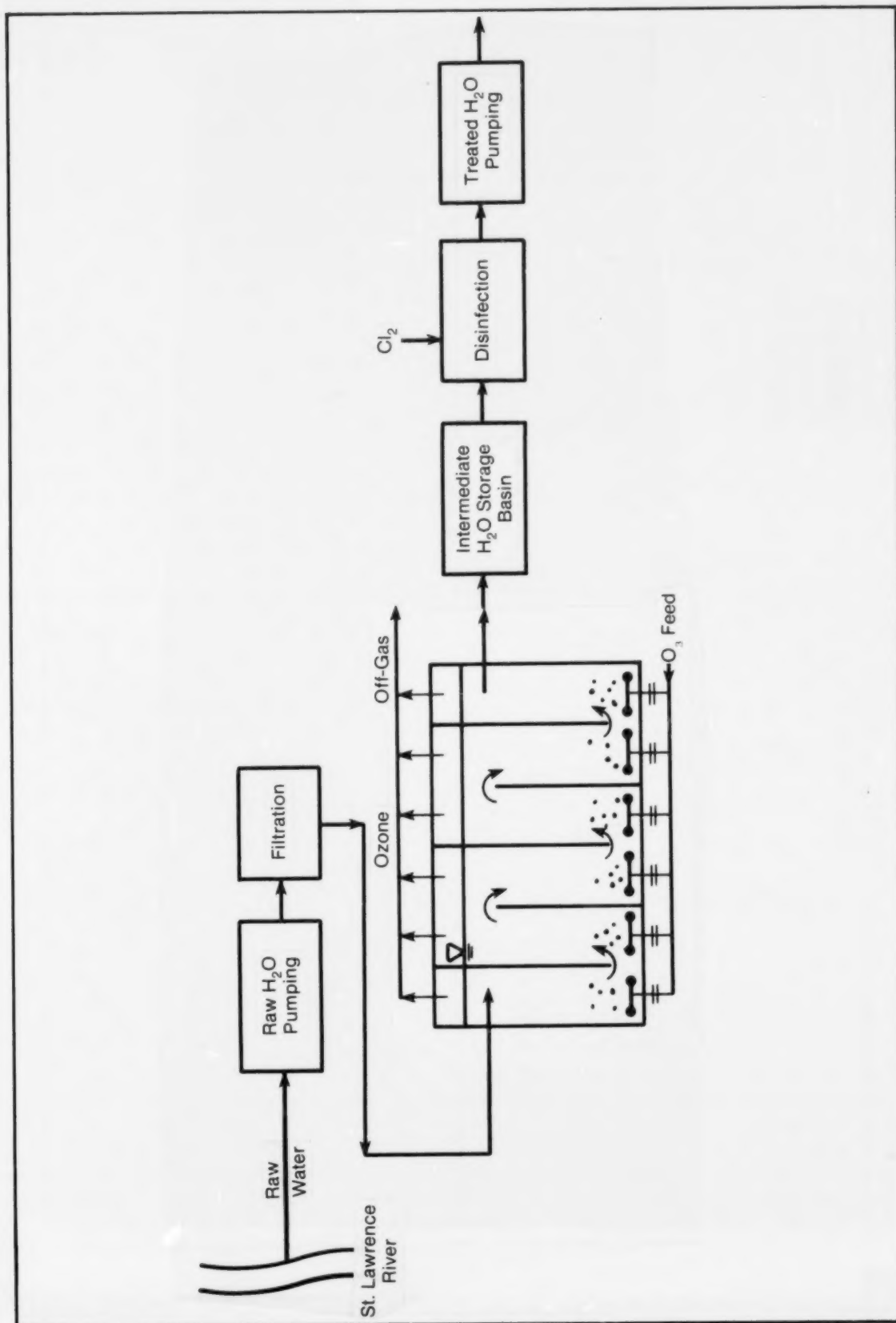


FIGURE 42 PLANT FLOW DIAGRAM

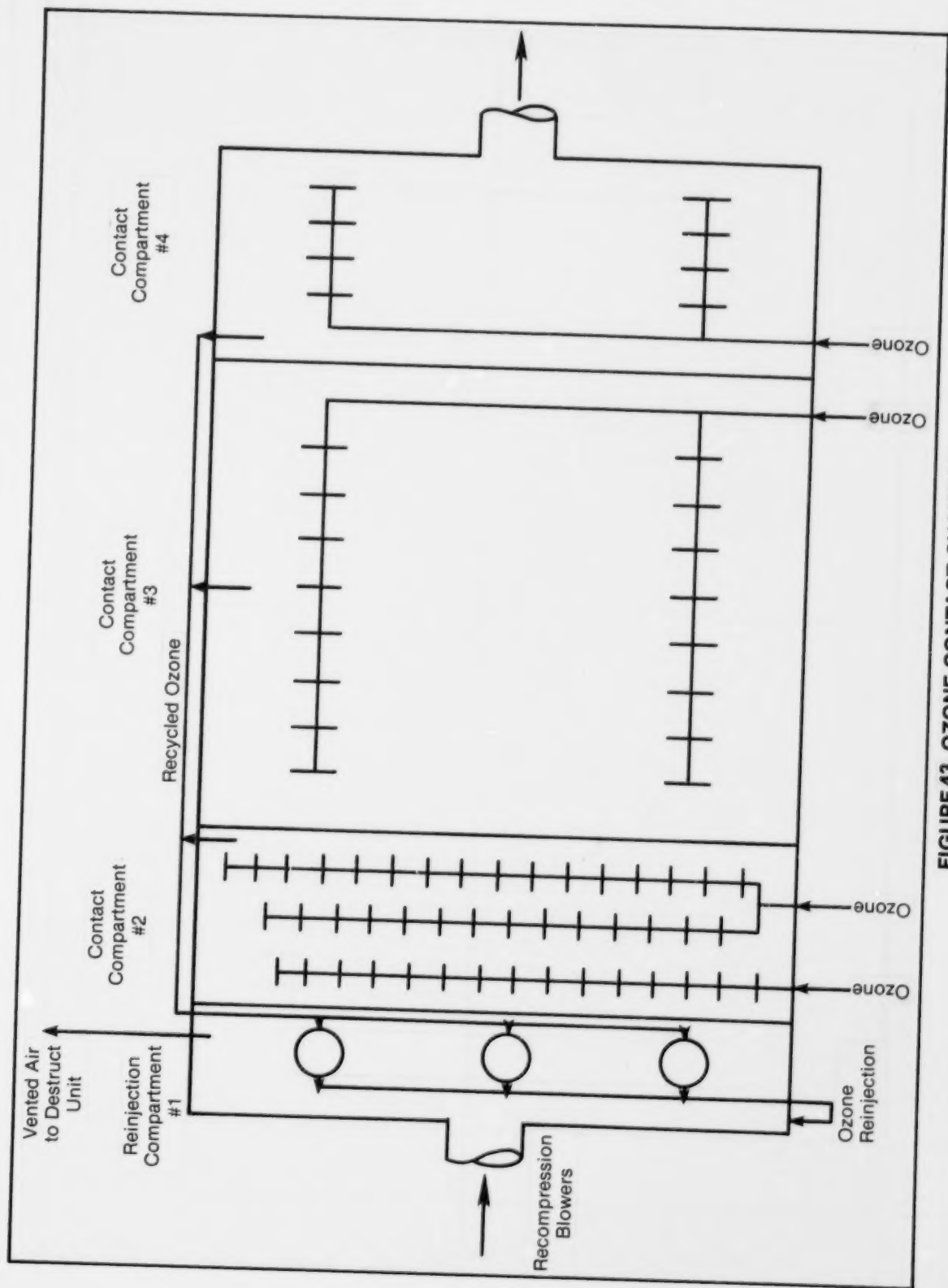


FIGURE 43 OZONE CONTACT CHAMBER

Ozone that collects in the tops of the contact chambers is recycled to the inlet of the chambers by recompression blowers; there are three recompression blowers per contact chamber. The recycled air/ozone mixture is re-injected into the first stage by a submerged Hoffmann turbine. An evacuation blower, rated at 10,000 cubic meters per hour, pulls air from the last stage of each contact chamber to create a negative pressure within the contact system. The residual air remaining after re-injection is then vented to an ozone destruct unit prior to its release into the atmosphere.

In order to reduce power consumption, simplify the maintenance of the ozonators, and prevent the incidence of a malfunction, it is necessary to filter and dry the air supply to a -55°C dew point prior to its injection into the ozonators. The air preparation system includes:

- Three compressors, each having a 1,500 to 5,000 cubic meter per hour capacity.
- Primary coolers.
- Refrigerating units.
- Activated alumina dryers.
- Micro filters having 5 micron meshes or less.

Off-gas from the ozone contact chamber is vented to a thermal destruct unit. The unit includes a preheater and a thermal destruct chamber. The discharge from the destruct unit is vented to the atmosphere.

The main ozone panel, located in the generator room, contains the primary controls and instruments used to monitor and regulate the ozonation process. It also contains the annunciator alarm panel. There are two control panels, one that monitors the ozone system and one that monitors the electrical system. A micro processor, located in the control panel, interfaces with the main plant computer for process control.

FACILITY OPERATIONS

Ozone System Control

The ozonation system at the Charles J. Des Baillets facility was designed to provide an ozone dose of 2 mg/L. The plant's contactors are operated in parallel and are taken on-and off-line

as required to maintain a total hydraulic detention time of 5 minutes. Ozone is injected into porous, ceramic diffusers installed in compartment Nos. 2, 3, and 4 of the contact chambers. The ozone flow rate to each of the compartments can be individually controlled. Currently, 60 percent of the ozone flow is directed to compartment No. 2, while the remaining 40 percent is evenly distributed between compartment Nos. 3 and 4.

The ozonation system feed rate is automatically controlled according to raw water flow and ozone residual (maintained at 0.4 mg/L) in the contactor effluent. The ozonation system is controlled and monitored by an on-site Honeywell computer. The output of ozone from the generators, when in the automatic mode, is controlled by varying the power to the generators, thereby increasing or decreasing the ozone concentration. The ozone concentration in the gas stream to the contact chambers is monitored by an on-line UV photometer manufactured by Dasibi. The operator can control the operation of the inlet air compressor, refrigerant dryer system, desiccant dryer system, ozonator system, and thermal destruct system from the main computer console.

All sub-systems of the ozonation process (i.e., compressors, refrigerant dryers, desiccant dryers, ozonators, recompressors, etc.) have their own control systems, which are monitored by the main computer. Each sub-system can be operated in the automatic or manual mode and contains all the interlocks necessary to shut down the system should a malfunction occur. The ozonators are designed to shut down if the dew point of the feed air exceeds -50°C.

Start-up and Operational Problems

The ozonation system was started-up in 1979. One of the initial difficulties experienced involved a malfunction with the inlet compressor heat exchanger. One of the water tubes within the heat exchanger ruptured and the ozone system was flooded with water before the unit could be isolated. This malfunction required replacing 580 (i.e., 50 percent) of the dielectrics in 4 of the plant's ozonators. The cause of the heat exchanger malfunction was not determined.

The ozone system generates considerable noise and the equipment is not installed in a sound-proofed area. As a result, the operators must wear ear protection when working around the equipment.

Problems were also experienced with the recompression blowers. Due to improper installation, the bearings in the units deteriorated due to ozone attack. It was determined that the teflon seals were not seated properly to protect the bearings. In addition, excessive vibration was experienced with these units due to inadequate frame size, even though vibration dampeners were installed. These problems affected all 18 of the recompression blowers, and it is anticipated that these blowers will eventually be removed from the system.

Problems were also experienced with the ozone gas-monitoring equipment. Equipment from three different manufacturers was tested at the facility; however, all the units were very unreliable and required frequent calibration (as often as once per day). Plant personnel are continuing their search for a reliable monitoring instrument.

The thermal destruct unit also experienced some minor problems. The thermal wheel, which preheats the gas prior to the oven destruct unit, was of welded construction; however, improper spot welding on the face plate caused the unit to seize. The thermal wheel was subsequently rewelded across the entire face plate and there have been no additional problems with this unit.

Problems were also experienced with the dew point instrument supplied with the drying tower. Due to erratic readings, a manual dew point determination is performed once per week to check the dew point hygrometer.

The most serious problem to date involves the operation of the three-way valves associated with the operation of the desiccant drying towers. These valves are currently out of service due to dirt accumulations within the valve body which are believed to have been caused by desiccant carry-over from the towers. In addition, it is suspected that the wrong lubricating grease was used on the valves. The ozone system was not on-line during the plant visit due to the problem with these valves.

Other minor start-up problems included electrical adjustments to the SCR drives on the inlet air compressor motors, and the replacement of a 225-amp circuit breaker on a regenerating heater element due to loose connectors which burned out the circuit breaker.

Operations and Maintenance Staff

Operator motivation and interest in the ozone disinfection system was excellent during the plant visit. The facility maintains an adequate staff (six mechanics, six electricians, and six instrumentation technicians) to perform the required maintenance on the total system. The operators showed an interest in the instrumentation; however, they were reserved in their attitudes due to the complexity and apparent unreliability of the instrumentation. Considering all of the above limitations, the facility engineer feels that once the design deficiencies are corrected, the system should perform adequately.

The La Salle facility maintains a well-equipped process control and research laboratory. Physical, chemical, and bacteriological tests for color, taste, turbidity, metals, micro-pollutant traces, etc., are performed on a daily basis. Samples of raw water, filtered water, ozonated water, final chlorinated water, and water from various points in the city's water distribution system are routinely collected and analyzed.

MAINTENANCE

A routine maintenance schedule has been implemented by facility personnel. A spare-parts inventory for the ozone system has not yet been compiled since the equipment is still under the manufacturer's warranty.

As part of the routine preventive maintenance performed on the mechanical equipment (motors, gear reducers, etc.), the ozonator dielectrics are cleaned once every three years. The cleaning method used includes initial cleaning with a soap solution followed by a methanol rinse and air drying. The operators wear gloves to avoid leaving dirt marks on the dielectrics, which can affect ozone generation and dielectric life.

The system's recompression blowers have proven to be high maintenance units. The bearings in these blowers have had to be manually repacked once every three months to avoid early failure. These bearings were also fitted with a pressurized air line to ensure that the teflon seals were seated. In addition, the recompression blowers are belt-driven units, and the frames which support the motors are too small, resulting in excessive vibration. Due to the high maintenance requirements for these units, they will be taken off-line in the future.

The residual ozone analyzers are calibrated once a week to ensure consistent micro-processor computer control of the ozonation process.

OPERATIONS AND MAINTENANCE COSTS

The operation and maintenance costs associated with the ozonation system are tabulated in Table 26. The costs are based on the operation of three ozone generators at 100 percent capacity, one inlet compressor operating at 194 kw, and one cooling-water pump (25 hp) operating at 18.6 kw. Each ozonator requires 300 kw, with one regenerating unit in service at 100 kw. Cooling-water requirements are approximately 660 gpm for the three ozone generators. Labor requirements include two mechanics, one instrument mechanic, and 0.5 electricians per year. The operating staff requires approximately two hours per day (total) to monitor the system. Supervision is limited to three hours per week.

Table 26

Charles J. Des Baillets Water Plant
Ozone System Cost Sheet

O₃ Generation Rate = 1,740 kg/d at 2.2 mg/L
FCI = \$7,000,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power			
Compression	3.1	2.4	7
Regeneration	1.4	2.4	3
Generation	12.4	2.4	30
Destruct	1.2	2.4	3
Cooling Water	0.26	2.4	1
	Mgal/kg	¢/Mgal	
Cooling Water	0.55	31	17
Operating Labor (.35 MY)			1
Repair Labor			12
Supervision (.075 MY)			1
Repair Materials (1% FCI)*			11
Supplies (10%) (O.L. + R.L. + Supv.))*			<u>1</u>
Total Operating Cost			87
<u>Overhead Cost</u>			
Insurance (None)			---
Amortization (7% at 20 years)			<u>104</u>
Total Overhead Cost			104
TOTAL OZONE COST ¢/kg (¢/lb)			191 (86)

MY, Man year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor
R.L., Repair Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

CITY OF PIERREFONDS WATER FILTRATION PLANT
PIERREFONDS, QUEBEC, CANADA

GENERAL

The Pierrefonds Water Filtration Plant was constructed in 1975 and is located approximately 25 miles west of Montreal (see Figure 44) on the Des Prairies River. The plant's average design flow is 25 mgd.

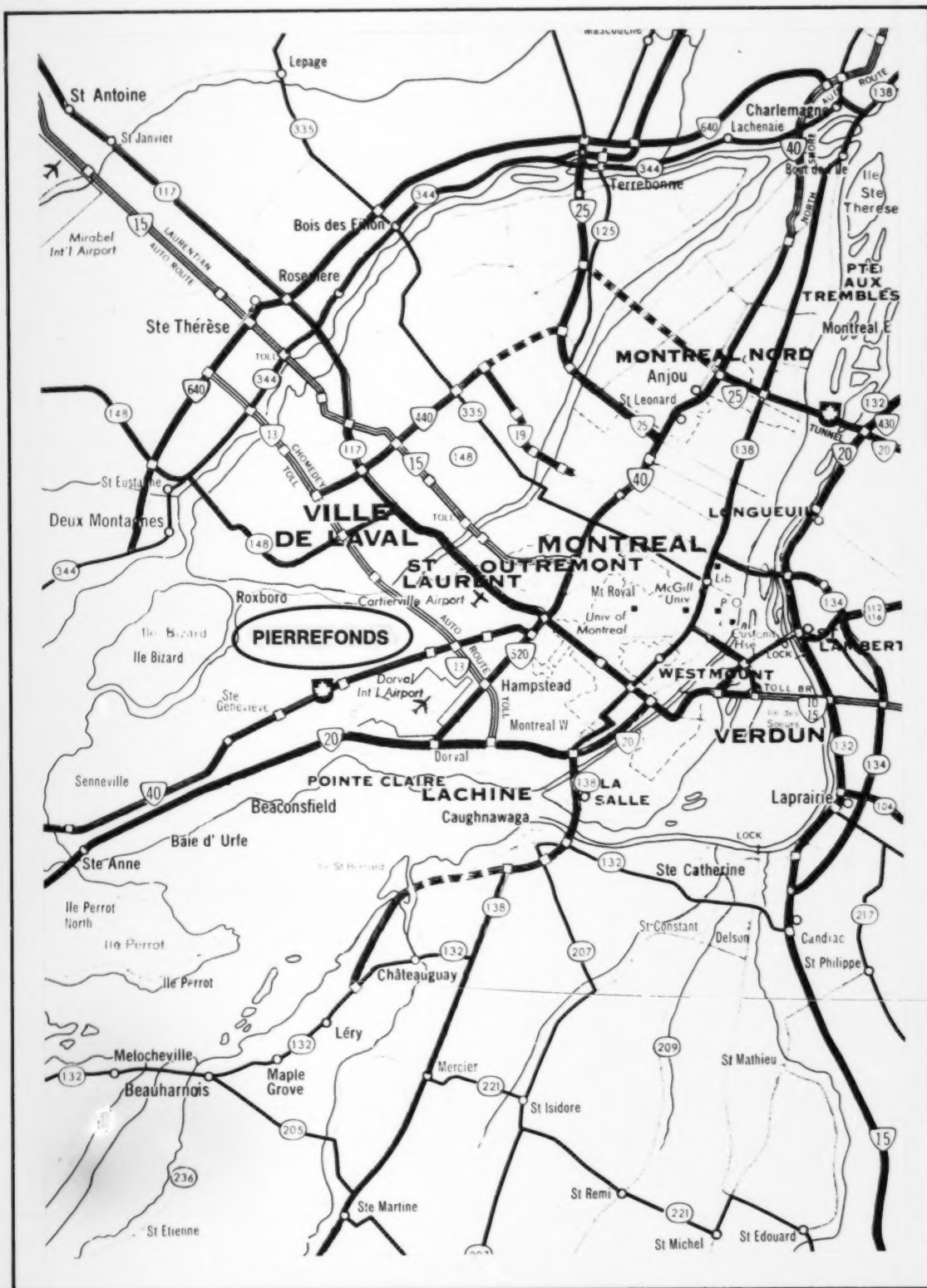
The pierrefonds plant currently treats an average flow of 15 mgd. The plant's treatment scheme incorporates raw water screening and pumping, flocculation, settling, filtration, ozonation for disinfection and taste and odor control, and chlorination to maintain a residual disinfectant concentration in the distribution system. A plant flow diagram is shown in Figure 45.

OZONE SYSTEM DESCRIPTION

Ozone is produced by four Trailigaz horizontal-tube, water-cooled ozonators. Each ozone generator contains 240 dielectrics and is rated at 102 lb/day of ozone at a maximum concentration of 1.3 percent. Two ozone generators are currently required to meet the plant's ozone demand of 2.4 mg/L. Ozone is fed into two contact chambers. Each contact chamber is divided into two compartments; compartment No. 1 is used for oxidation of taste and odor compounds and compartment No. 2 is used for disinfection and virus inactivation. The contact chambers provide a 4-minute detention time at the design flow rate of 25 mgd. Ozone is fed into the contact chamber through a series of ceramic diffusers. There are 51 ceramic diffusers located in each compartment, and each diffuser is 3 in. o.d. by 1.5 in. i.d. by 117 in. long. Residual ozone monitors are installed in each compartment of the contact chamber; however, only the second stage residual is normally monitored for process control. Ozone that collects in the top of the contact chambers is vented through an ozone destruct unit to the atmosphere by an evacuation blower.

The ozonation system includes:

- Three compressors.
- Primary coolers.
- Two refrigerating units.
- Two activated alumina desiccant drying towers.
- Microfilters, having five-micron mesh or less.



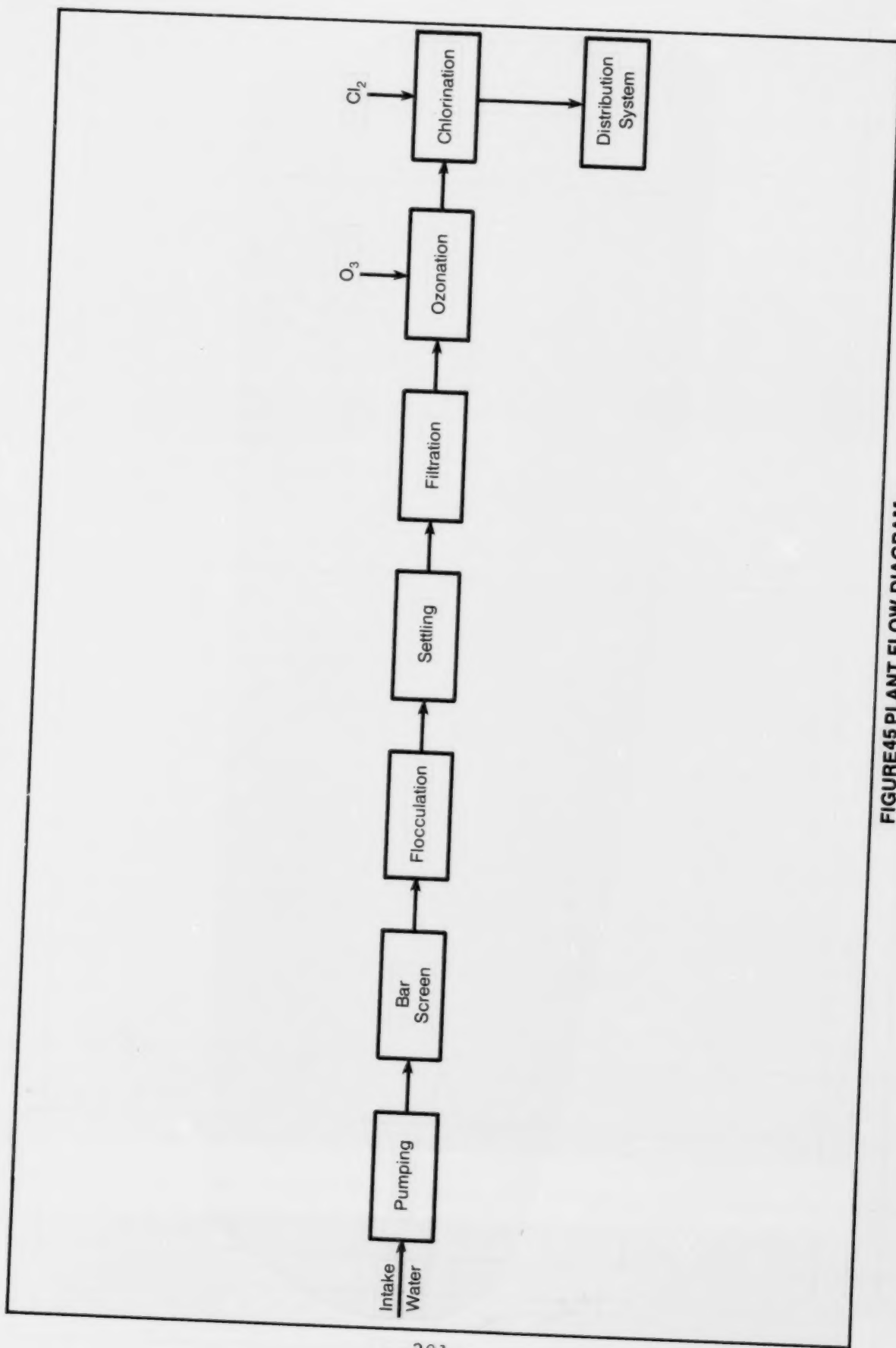


FIGURE 45 PLANT FLOW DIAGRAM

Ozonator Controls

The main ozone panel is located in the generator room and contains the primary controls and instruments used to monitor and regulate the ozonation process. It also contains the enunciator alarm panel. There are two control panels, one that monitors the ozone system and one that monitors the electrical system. There is an individual control panel for each ozonator.

Compressed air is passed through one tower to be dried while the other tower is being regenerated. To regenerate a tower, a 1.0-kw heater heats the dryer for a maximum of 3.5 hours and then is cooled for a minimum of 2.5 hours. After 6 hours, a pneumatic valve, activated by the air pressure of the compressor, causes the dryer towers to switch and restarts the 6-hour cycle on the opposite tower. The dryer operation is fully automatic.

Particle Filter

A 20-micron filter, manufactured by Filterite, removes desiccant particles from the air dryer discharge.

Water Pump

The water pump, a Dean Brothers 3-4 DLSS, delivers 11 gpm of water at a pressure head of 70 ft to the ozonator for use as cooling water.

Electronics Cabinet

The electronics cabinet contains the inverter circuit and the ozone generator controls. The inverter rectifies AC input power to DC and then reconverts it to high frequency AC. The ozone output is controlled by varying the frequency of the inverter. The 115-V control circuit operates all interlocks, valves, and other controls in the ozonator.

HVT Transformer

The high voltage transformer, an NWL 26207, has a rating of 33 kva. The primary is connected to the output from the inverter. The rmf of the secondary is approximately 8,000 volts. The high voltage is utilized to generate ozone in the cell.

HV Coolant Pump

The coolant pump, a March Mfg. Model TE-5C-MD, has a 1 to 4 hp, single-phase, 115-V, 60-Hz, totally enclosed motor. It is used to circulate the HV coolant through the ozonator cells and the electronics cabinet.

Heat Exchanger

The system heat exchanger, an American Standard Model 03-036, is used to cool the HV coolant circulated through the ozonator.

Ozone Gas Destructor

The ozone destruct system thermally decomposes the excess ozone in the exhaust from the ozone contact chamber by heating the off-gases to 650°F. The major system component includes a General Electric Calrod Circulation Heater Type No. JL-1115. The heater is a 480-V, three-phase, 4.5-kw heater. It has a 3-in. diameter stainless steel body and flange, and 321 stainless steel calrod. It is capable of heating 20 scfm of air from 70°F to 650°F. During normal operation, the inlet temperature to the heater is about 350°F.

The preheater to the unit is an American Standard Model 05-014. The preheater is a stainless steel air-to-air heat exchanger. The exhaust from the contact chamber enters the tube side of the heat exchanger and exits at a temperature of about 350°F. The air from the heater enters the shell side of the heat exchanger and is then discharged to the atmosphere.

Main Ozone Panel

The main ozone panel is incorporated with the ozone generator skid. It contains the major controls and instruments used to monitor and regulate the operation of the ozonation system. The control mode is selected by a four-position rotary switch:

- Remote On/Off - The ozonator is turned on and off from a remote location.
- Off - The ozonator is off.
- On - The ozonator is on.
- Air Prep Only - Only the air preparation system is on.

A manual ozone output control potentiometer is mounted on the control panel. This controls the ozone output by varying the DC current to the inverter. The ozone output is proportional to the current.

An automatic/manual toggle switch is provided so that the ozonator may be operated in either mode. In the automatic mode, the ozonator is controlled by the operation of the wastewater feed pump feeding the filtration system which precedes the ozone contact chamber. In the manual mode, the ozone production rate of the ozonator is controlled by a manual ozone output control. An emergency shut-down, red push/pull button is provided and will shut down all power to the ozonator when pressed.

The following internal interlock sensors are provided with the unit:

- Flow Switches - The flow switches sense the flow of air and HV cooling water through the ozonator. If the flow is insufficient, it causes the interlock to activate and shut down the ozonator.
- Temperature Sensor - This senses the temperature of the ozone discharge from the ozonator. If the temperature is too high, it causes the interlock to activate.
- Dew Point Sensor - This senses the dew point of air going to the ozonator. If the dew point is too high, an interlock will be activated.

FACILITY OPERATIONS

Ozone System Control

The ozonation system at the Pierrefonds facility was designed to provide an average ozone dose of 2.4 mg/L. The plant's contactors are operated in parallel for an average detention time of 5.5 minutes. The ozone flow rate to each of the compartments is individually controlled. Currently, two-thirds of the ozone flow is directed to compartment No. 1 (used for oxidation of taste- and odor-producing compounds), while the remaining one-third is directed to compartment No. 2 (disinfection and virus inactivation).

The ozonation system feed rate is manually controlled according to raw water flow and ozone residual in the contactor effluent.

The residual is maintained between 0.4 and 0.45 mg/L since virus inactivation does not occur at residuals less than 0.4 mg/L. Each ozonator is controlled through a five-position output switch. The output of ozone from the generators is controlled by varying the power to the generators through the five-step selector switch.

All sub-systems of the ozonation process (i.e., compressors, refrigerant dryers, desiccant dryers, ozonators, etc.) have their own control systems and contain all the interlocks necessary to shut down the system should a malfunction occur.

Start-up and Operational Problems

The ozonation system cost 1.3 million dollars and was started up in 1977. One of the initial difficulties experienced involved malfunctions with the inlet compressor heat exchanger. One of the water tubes within the heat exchanger ruptured and the ozone system flooded with water before the unit could be isolated.

Another problem involved the original heating elements in the desiccant drying towers which were constructed of mild steel and frequently broke. The heating elements were changed to stainless steel and there have been no problems since.

Operations and Maintenance Staff

Operator motivation and interest in the ozone disinfection system were excellent during the plant visit. The facility maintains an adequate staff to perform the required system maintenance. The Pierrefonds facility maintains a well-equipped process control laboratory where physical, chemical, and bacteriological tests for taste, color, turbidity, etc., are performed on a daily basis. Samples of raw water, filtered water, ozonated water, final chlorinated water, and samples from various points in the City's water distribution system are routinely collected and analyzed.

MAINTENANCE

A routine maintenance schedule has been implemented by facility personnel. A spare parts inventory for the ozone system is maintained and consists of spare dielectrics, desiccant media, and electrical parts. As part of the routine preventive maintenance performed on the mechanical equipment (motors, valves, etc.), the ozonator dielectrics are cleaned once per year. The cleaning method includes a methanol rinse followed by air drying.

OPERATIONS AND MAINTENANCE COST

The operations and maintenance cost associated with the ozonation system are tabulated in Table 27. The costs are based on the operation of two ozone generators at 100 percent capacity and one inlet compressor operating at 20 kw. The operating staff requires approximately 3 hours per day (total) to monitor the system. Supervision is limited to 1 hour per day.

Table 27

Ozone Cost Sheet
Pierrefonds Water Filtration Plant

O₃ Generation Rate = 135 kg/d at 2.4 mg/L
FCI - \$1,300,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power			
Compression	2.7	3.5	9
Regeneration	2.3	3.5	8
	Mgal/kg	¢/Mgal	
Water	.132	7.8	4
Operating Labor (0.5 MY)			22
Repair Labor (0.5 MY)			22
Supervision (.19 MY)			8
Repair Materials (.5% of FCI)*			15
Supplies			<u>5</u>
Total Operating Cost			93
<u>Overhead Cost</u>			
Insurance (none)			
Amortization (7% at 20 years)			<u>249</u>
Total Overhead Cost			249
TOTAL OZONE COST ¢/kg (¢/lb)			342 (154)

MY, Man Year (2,080 hrs)
FCI, Fixed Capital Investment

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

CITY OF SHERBROOKE WATER FILTRATION PLANT
SHERBROOKE, QUEBEC, CANADA

GENERAL

The Sherbrooke Water Filtration Plant is located in the eastern portion of the Province of Quebec approximately 144 miles southwest of the City of Quebec (see Figure 46). Construction of the plant began in 1976 and was completed in 1977. The plant's design hydraulic capacity is 113,500 cubic meters per day (30 mgd) and it currently treats an average flow of 59,000 cubic meters per day (15.5 mgd). A site visit was conducted on 21 April 1982.

The Sherbrooke plant's treatment scheme incorporates raw water screening and pumping followed by microstrainers, ozonation for disinfection and odor and color removal, and chlorination to maintain a residual disinfection concentration in the distribution system. A plant flow diagram is shown in Figure 47.

OZONE SYSTEM DESCRIPTION

Ozone is produced by four Degremont horizontal-tube, water-cooled ozonators. Each generator contains 126 dielectrics and is rated at 125 lb/day per ozonator at a maximum concentration of 10.0 mg/L. Two ozone generators are currently required to meet the plant's ozone demand. Ozone can be fed into three contact chambers; however, only two contact chambers are currently in use. Each contact chamber is divided into two compartments, each 11 ft wide by 22 ft long, with a 16-ft sidewater depth which provides a 4-minute detention time at the current flow rate of 59,000 cubic meters per day (15.5 mgd). Ozone is discharged into the contact chamber through a series of stone diffusers measuring 5 in. in diameter by 36 in. long.

There are 24 diffusers in the first compartment and 16 diffusers in the second compartment of each contact chamber. Residual ozone monitors are installed in each compartment of the contact chamber; these control the ozonators output to maintain a 0.2 mg/L residual in each compartment. Ozone that collects in the top of the contact chambers is vented to the atmosphere.

There are four rotary-screw compressors which are manifolded to the four generators. The ozonation system includes:

- Four compressors each rated at 125 cfm at 100 psig.
- Primary coolers (heat exchanger).
- Refrigerating units.

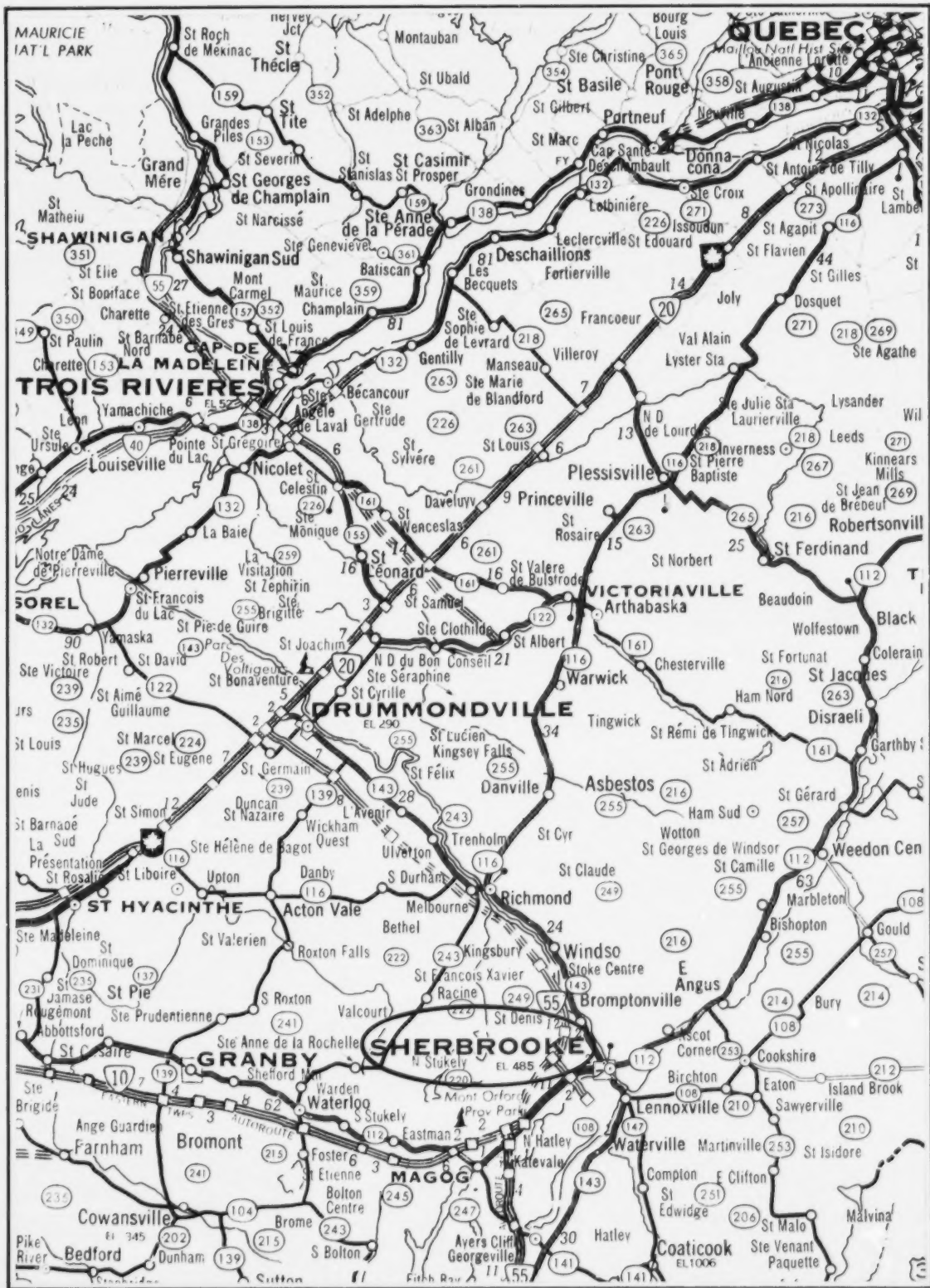


FIGURE 46 PLANT LOCATION MAP

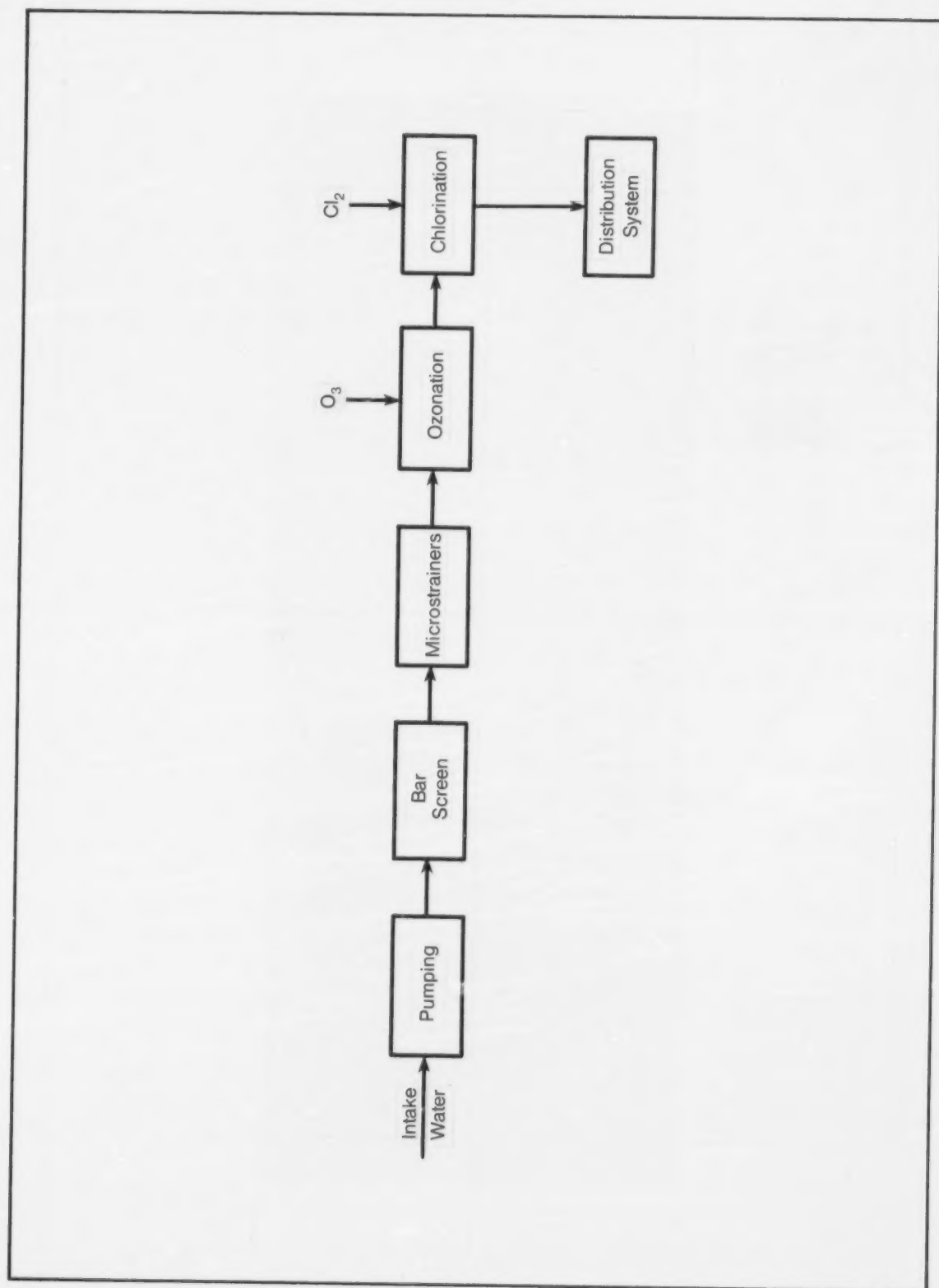


FIGURE 47 PLANT FLOW DIAGRAM

- Desiccant drying towers.
- Microfilters, having five-micron mesh or less.
- Four ozone generators, each rated at 125 lb/day.

Each ozonator has its own central control panel located next to the unit. Each control panel contains the primary controls and instruments used to monitor and regulate the ozonation process. It also contains the enunciator alarm panel.

FACILITY OPERATIONS

Ozone System Control

The ozonation system at the Sherbrooke facility was designed to provide an ozone dose of 2 mg/L. The plant's contactors are operated in parallel and are taken on- and off-line as required to maintain a total hydraulic detention time of 4 minutes. Ozone is injected into porous ceramic diffusers installed in both compartments of each contact chamber. The ozone flow rate to each of the compartments can be individually controlled. Approximately 75 percent of the ozone flow is directed into the first compartment while the remaining 25 percent is injected into the second compartment.

The ozonation system feed rate may be automatically controlled according to raw water flow and ozone residual in the contactor effluent. The ozone residual was initially maintained at 0.4 mg/L, however, the ozone residual set point has been reduced to 0.2 mg/L in order to realize cost/energy savings. The ozonation system is currently operated in the manual mode due to fluctuations in water quality. Residual ozone is continuously recorded on the main control panel, and the operators increase or decrease the output of ozone from the generators as required to maintain a 0.2 mg/L residual.

All sub-systems of the ozonation process (i.e., compressors, refrigerant dryers, desiccant dryers, ozonators, etc.) have their own alarm control systems which are part of the main console. Each sub-system can be operated in the automatic or manual mode, and each contains all the interlocks necessary to shut down the system should a malfunction occur.

Start-up and Operational Problems

The ozonation system was started up in 1979. One of the initial difficulties experienced involved the operation of the contact chambers. The ozone contact chambers are directly below the ozone generator room; therefore, ozone collected in the tops of

the contact chambers would leak into the generating room. An evacuation blower was therefore installed on the off-gas stacks to pull air from the last stage of each contact chamber in order to create a negative pressure within the contact system. Initial problems were also encountered with the diffuser gasket seals that had deteriorated, thereby causing large gas leaks and reduced ozone transfer efficiency.

Problems were also experienced with the ozonation electrical system. The transformers and capacitors were initially underdesigned and consequently burned out. The manufacturer replaced the damaged units with larger ones.

Operations and Maintenance Staff

Operator motivation and interest in the ozone generating system were excellent during the plant visit. The facility maintains an adequate staff to perform the required maintenance on the total system.

The Sherbrooke facility has a process control laboratory in which physical, chemical, and bacteriological tests for color, taste, turbidity, etc., are performed on a daily basis. Samples of raw water, filtered water, ozonated water, and treated water from various points in the City's water distribution system are routinely collected and analyzed.

MAINTENANCE

A routine maintenance schedule has been implemented by facility personnel. The 124 dielectrics in each generator are cleaned once every year. The cleaning method used is one of an alcohol wash followed by air drying which usually requires two man-days to complete. Each contact chamber is also dewatered and inspected once a year. The facility engineer is pleased with the operation of the system since it has required an average of only \$2,000 per year for spare parts for all four generators.

The residual ozone analyzers use the amperometric method to monitor ozone residual. The ion exchange between the gold and brass plates within the units relate to mg/L of ozone. The brass plate is replaced once per year at a cost of \$130. This is done to protect the gold plate which, if fouled, would cost \$800 to replace.

OPERATIONS AND MAINTENANCE COSTS

The operation and maintenance costs associated with the ozonation system are tabulated in Table 28. The costs are based on the operation of two ozone generators at 92 percent capacity and two inlet compressors operating at 44 kw. Each ozonator is regulated at 32 kw. Cooling water requirements are approximately 40 gallons per minute for the two ozone generators.

The operating staff requires approximately 4.5 hr/day (total) to monitor the system.

Table 28

Ozone Cost Sheet
Sherbrooke Water Filtration Plant

O₃ Generation Rate = 111.6 kg/d at 2.0 mg/L
FCI - \$560,000

Cost Item	Ratio kwh/kg	Price ¢/kwh	Cost ¢/kg
<u>Operating Cost</u>			
Electric Power			
Compression	9.6	3.0	29
Generation	13.8	3.0	41
	Mgal/kg	¢/Mgal	
Water	0.51	9.0	4
Operating Labor (.82 MY) (4.5 hr/day) @ \$9.80/hr			39
Repair Labor (.05 MY) (10 m-d) @ \$9.80/hr			2
Supervision (.08 MY) @ \$22,000/yr			4
Repair Materials (Max. \$2,000/yr)			5
Supplies [10% (O.L. + R.L. + Supv.)]*			5
Total Operating Cost			129
<u>Overhead Cost</u>			
Insurance (none)			---
Amortization (7% at 20 years)			130
Total Overhead Cost			130
TOTAL OZONE COST ¢/kg (¢/lb)			259 (116)

MY, Man Year (2,080 hrs)
FCI, Fixed Capital Investment
O.L., Operating Labor

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J., EPA-600/9-79-018, 1979.

SENTS CREEK WASTEWATER TREATMENT PLANT PELLA, IOWA

GENERAL

Pella is located in the central portion of southern Iowa, approximately 40 miles southeast of Des Moines (see Figure 48). The existing treatment facility was constructed in 1981 at a cost of 9.6 million dollars. The plant started operation on 9 November 1981, and replaced several smaller plants scattered throughout the county. A site visit was conducted on 5 May 1982.

The Pella plant (7.0 mgd design flow) currently treats an average flow of 1.5 mgd. The plant's treatment scheme incorporates maceration, grit removal, primary clarification, single-stage activated sludge, clarification, and UV disinfection. The plant's sludge-handling system employs two-stage anaerobic digestion and disposal via land application of liquid sludge. A plant flow diagram is shown in Figure 49.

The plant's final effluent discharges into Sents Creek. At the time of the plant visit, the facility was less than one year old and did not have an approved NPDES permit. The proposed plant discharge limits are presented in Table 29.

ULTRAVIOLET (UV) SYSTEM DESCRIPTION

The Pella plant utilizes a Pure Water Systems ultraviolet (UV) irradiation system for disinfecting secondary clarified effluent. A schematic representation of Pella's UV disinfection system is shown in Figure 50. Wastewater flows through two parallel disinfection chambers, each designed to provide 2.1 seconds contact time at a flow of 15, 100 m³/day (4 mgd). The dimensions of each bank of UV lamps are 22 in. x 22 in. x 5 ft. Two parallel UV disinfection chambers are used at the Pella plant (see Figure 50). Each contacting chamber contains 196 evenly-spaced lamps. These lamps are divided into 3 banks of 70, 70, and 56 lamps each. The outer quartz tubes are spaced 1/2-in. apart, providing 1/4 in. of radiation penetration for each tube. Each bank of lamps has individual electrical connections, and each lamp has a separate Light Emitting Diode (LED) to indicate whether the respective lamp is operating.

A 3-phase powerstat controls the input voltage to the UV lamps from 40 to 100 percent. The powerstat is controlled by a micro processor with manual override. A micro processor modulates power in response to plant flow and UV dosage.

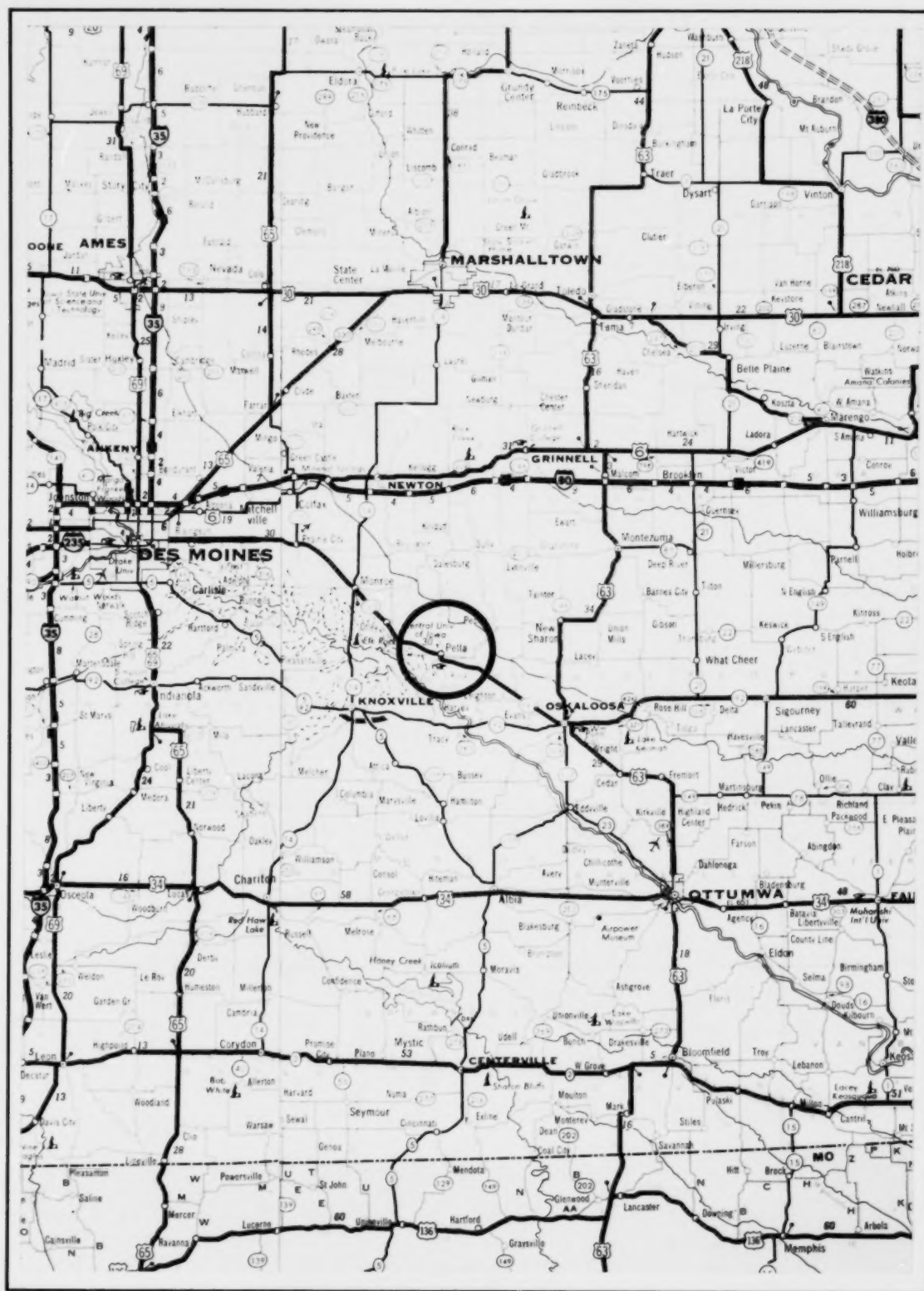


FIGURE 48 PLANT LOCATION MAP

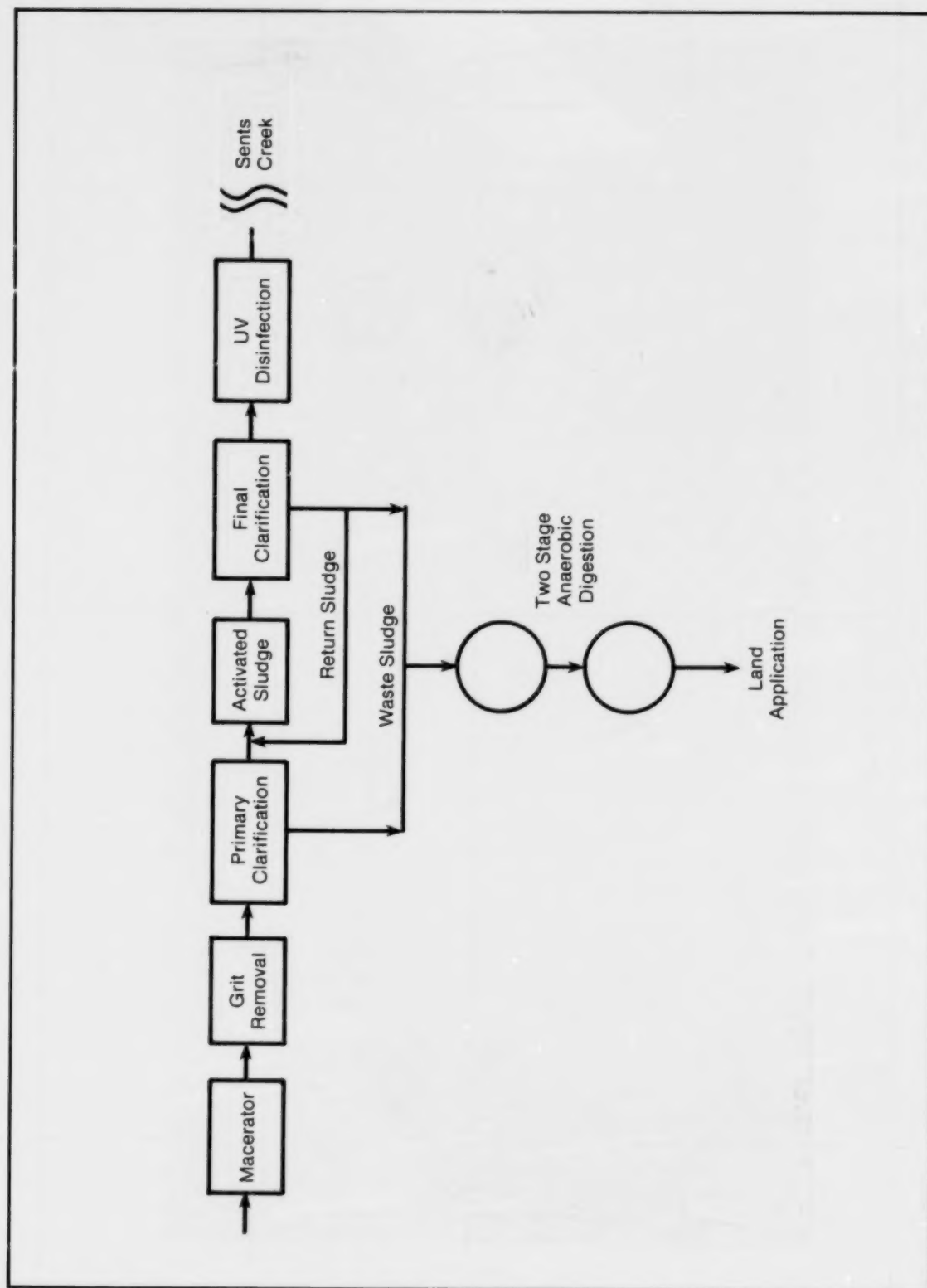


FIGURE49 PLANT FLOW DIAGRAM

Table 29

Proposed NPDES Permit Limitations
Sents Creek Wastewater Treatment Plant
Pella, Iowa

Parameter		Concentration
BOD ₅ ,	Monthly Average	30 mg/L
	Monthly Maximum	45 mg/L
TSS,	Monthly Average	30 mg/L
	Monthly Maximum	45 mg/L
Ammonia-Nitrogen, Summer		10 mg/L
Winter		15 mg/L

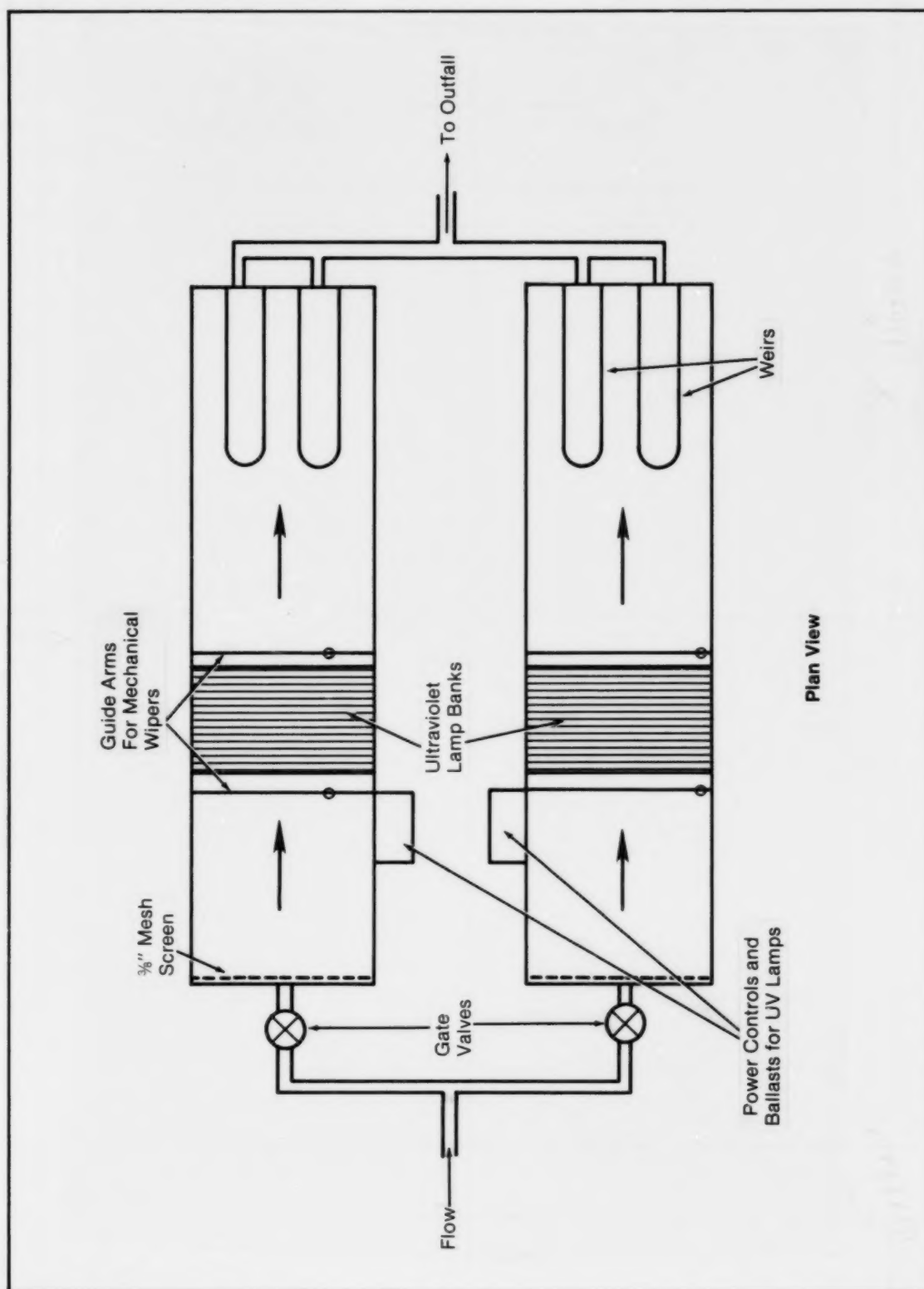


FIGURE 50 ULTRAVIOLET DISINFECTION UNITS

The UV dosage is varied automatically by fluctuations in effluent flow or by manually setting the voltage powerstat between 40- and 100-percent output. The system currently does not include UV sensors; burned-out lamps are indicated by the LED's located on each lamp which fail to light upon malfunction of the lamp.

Each UV lamp is rated at 100-watts input and 40-watts output at 240 nm. The lamps are 5 ft 4-1/2 in. long and have a 1/2-inch O.D. The end caps of the lamps are made of epoxy diallyl phthalate. Each lamp can be replaced without dewatering the disinfection chamber by unscrewing a lamp end-plate and sliding the respective lamp out of the quartz tube enclosure.

The outer surfaces of the quartz tubes are cleaned by a mechanical wiper fitted with teflon O-rings. The frequency of lamp wiping can be regulated by setting a timer located in the power control box. Under current operation, one pass of the wiper arm is activated every two hours. The effectiveness of cleaning is indicated by the subsequent decrease in fecal coliform count achieved. A sketch of the mechanical cleaning mechanism is shown in Figure 51.

FACILITY OPERATIONS

UV System Control

The four options available for system operation and control are described as follows:

- The output of each lamp can be varied proportional to effluent flow via an instrumentation control loop between the effluent flow meter and the UV powerstat. To date, this option has not been installed by the manufacturer.
- The system powerstat can be manually set between 40- and 100-percent output at the power control box. This was the mode of operation being utilized during the plant visit.
- Each of the three banks of lamps can be individually shut down to decrease the system's total UV irradiation output.

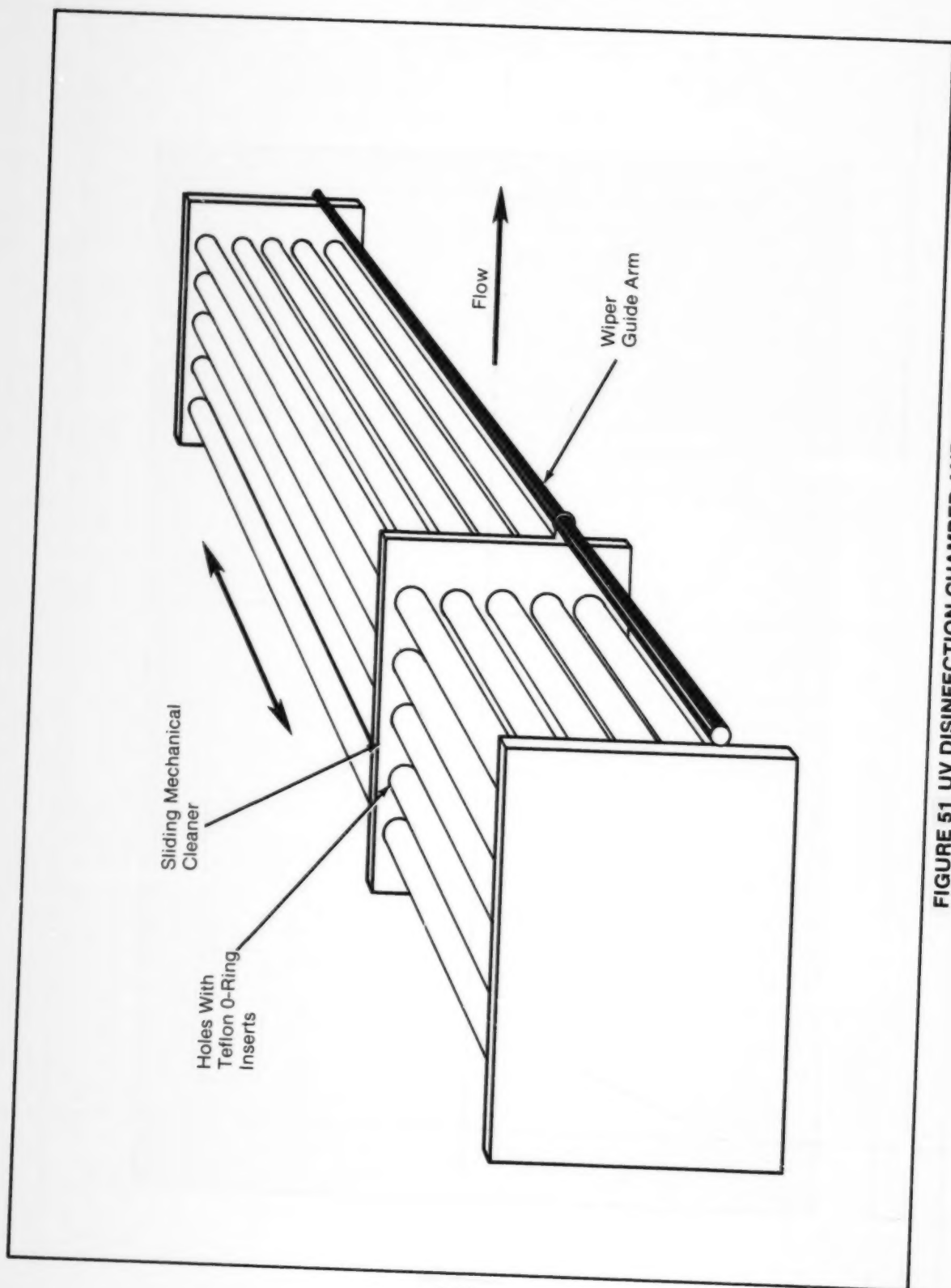


FIGURE 51 UV DISINFECTION CHAMBER AND MECHANICAL CLEANING MECHANISM

- Flow can be diverted to either one of the system's two disinfection chambers, or both can be used simultaneously. This provides the flexibility to use just one UV chamber during low flow periods, thereby minimizing power usage. (Only one chamber is presently used since the actual flow is approximately 20 percent of the design flow.)

Start-Up and Operational Problems

The only start-up problem reported by the operating staff occurred when the inlet valves to the UV disinfection chambers were initially opened too quickly and the resultant flow surge through the tube banks was great enough to rupture many of the outer quartz tubes. It is believed that if the wiper mechanism had been placed in the middle of its path, sufficient structural support would have been provided for the tubes and their breakage, due to the high velocity flows, would have been avoided.

Problems with the powerstat have also occurred during operation of the UV disinfection system. It has been determined that if the setting on the powerstat is below 75 percent, the lamps will not light; therefore, the power setting must be maintained above 75 percent in order to operate the UV disinfection system. This higher power setting results in excessive electrical power consumption.

LED failure has also prevented accurate monitoring of lamp operation. Frequently, even though an indicating LED was not lit, it was discovered that the corresponding UV tube was still operational. Therefore, when an LED goes out, the operator has to continually check each LED and then check the tubes to make sure the correct indication is being given by the LED.

Problems have also been encountered with the UV cleaning mechanism, which tends to jam if the mechanism is not routinely used. At times, the cleaning mechanisms can be fixed by simple operator attention; however, the manufacturer must be called frequently to repair the mechanism.

MAINTENANCE

The UV disinfection units require little maintenance other than operational checks on the status of the lamps and wipers. Wiper operation should be observed at least once during each 8-hour shift. This procedure consists of simply ensuring that the wiper mechanism is operational and that the mechanism counter has

advanced. Should the wiper fail, the efficiency of the unit will gradually decrease.

The manufacturer recommends that lamp status checks be made at 24-hour intervals. Lamp status can be confirmed by observing the pilot lights (LED's) located within the power supply enclosure. Should the pilot lights indicate that one or more lamps are non-operational, this condition should be confirmed by visual observation (from the service pit) of the lamps in question. In addition, the power supply ventilation fans should be checked periodically; fans should be running whenever the power supply is on.

OPERATIONS AND MAINTENANCE COSTS

Operations and maintenance costs could not be formulated because sufficient data has not been collected and operational experience has not been gained by the plant's staff. This is due to the existing two-year manufacturer's warranty under which the service agent performs all necessary repairs and maintenance to the system.

SANFORD WASTEWATER TREATMENT PLANT
SANFORD, MAINE

GENERAL

Sanford is located in the southwestern portion of Maine, approximately 45 miles southwest of Portland (see Figure 52). The town's original wastewater treatment facility was constructed in 1961 and utilized a stabilization pond treatment process. The plant was upgraded in 1981 to a two-stage AWT facility. A site visit was conducted on 15 April 1982.

The Sanford plant (3.6 mgd design flow) currently treats an average flow of 2.5 mgd. The plant's treatment scheme incorporates screening, raw sewage pumping, grit collection, secondary treatment utilizing aerated lagoons, polishing lagoons, intermediate pumping, flocculation (alum addition for phosphorus removal), clarification using lamella separators, tertiary filtration, and disinfection by UV radiation. The plant's sludge handling system employs gravity thickening and belt-press filtration. A plant flow diagram is shown in Figure 53.

The plant's final effluent discharges into Mousam Creek, a tributary stream which flows into Estes Lake. The estimated seven-day, ten-year minimum flow for Mousam Creek is 10 cfs; thus, stringent NPDES discharge limitations have been imposed on the Sanford plant. The plant's discharge limits are presented in Table 30.

UV SYSTEM DESCRIPTION

The Sanford plant utilizes UV radiation for disinfecting final effluent. In this process, the plant effluent is irradiated with energy from UV light sources operating at a wave length of 254 nm.

The Aquafine UV disinfection system includes the following major components:

- Two UV irradiation modules.
- Remote control console.
- CRT programmer.

Each module consists of a stainless steel disinfection chamber and a steel ballast enclosure. The ballast enclosure is mounted on top of the disinfection chamber and houses the lamp ballast,

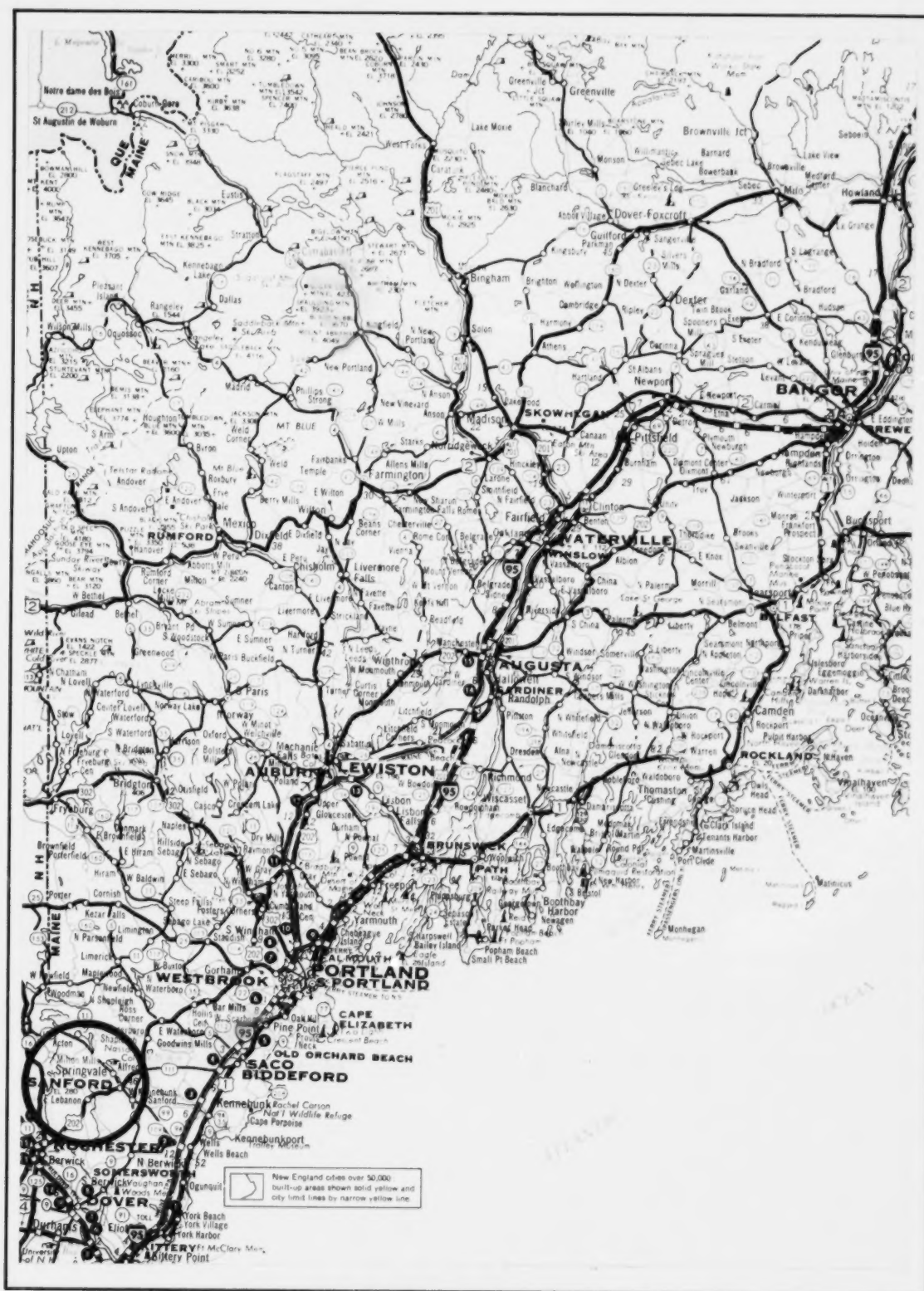


FIGURE 52 PLANT LOCATION MAP

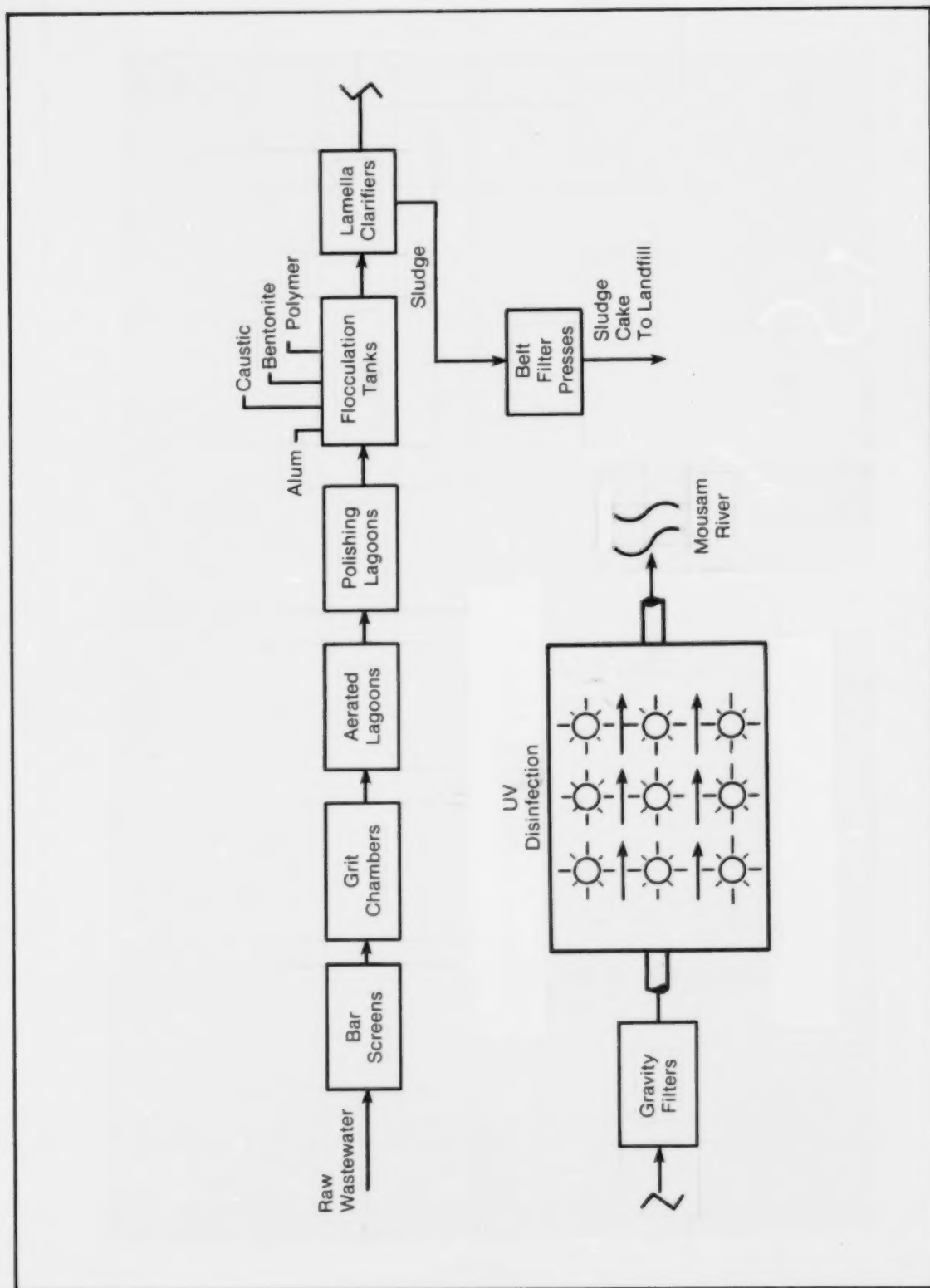


FIGURE 53 PLANT FLOW DIAGRAM

Table 30
NPDES Discharge Limitations¹
Sanford Wastewater Treatment Plant
Sanford, Maine

Effluent Characteristics	Monthly Average kg/day (lbs/day)	Weekly Average kg/day (lbs/day)	Maximum Day kg/day (lbs/day)	Sample Type	Monthly Average	Weekly Average	Maximum Day	Monitoring Frequency
Flow, cu m/day (mgd)	** 150 (330)	** ---	** 250 (550)	Daily, avg. Min., max.	16,654 (4.4)	**	**	Continuous
Biochemical Oxygen Demand, 5-day, 20°C	---	---	---	24 hr.	9 mg/L	---	15 mg/L	3 x weekly
Total Suspended Solids	---	---	---	Composite	9 mg/L	---	15 mg/L	3 x weekly
Settleable Solids	---	---	---	24 hr.	---	---	---	---
Fecal Coliform Bacteria	---	---	---	Composite	---	0.1 ml/L	0.1 ml/L	3 x weekly
Total Phosphorus	8 (18)	---	17 (37)	Grab	60/100 ml	60/100 ml	60/100 ml	1 x weekly
pH		---	6.5 to 8.0	Grab	0.5 mg/L	---	1.0 mg/L	1 x daily

¹ Effluent limitations from 1 December 1981 to 31 December 1986.

running time meters, and Light-Emitting Diode (LED) monitoring assemblies for section operation. The disinfection system (see Figure 54) includes four parallel operating sections, each of which contains 32 UV lamps spaced two in. apart. The UV lamps are 5 ft long and extend across the flow path. Each lamp is housed within a pure fused-quartz sleeve, which protects the lamp from moisture and acts as a temperature buffer. Two motorized wiper assemblies per module operate automatically to clean the quartz sleeves. Two ethylene propylene rubber (EPR) wiper assemblies, located at 12-in. intervals, move back and forth across the disinfection chamber, cleaning debris off the quartz sleeves.

Each module has a hydraulic capacity of 1,550 gpm (2.17 mgd). Effluent from the gravity filters is irradiated for approximately 1.5 seconds at the design flow rate. The overall dimensions of the module are approximately 6 ft wide by 7 ft long by 6 ft high.

The disinfection modules are operated from a remote control console which contains the operating control switches, monitoring instruments, warning lights, and control logic circuitry (Energy Management System) for automatic program operation. A separate CRT programmer is supplied for programming the system.

Also included in the disinfection chamber is an automatic water-level control mechanism. This allows the water level within the disinfection chamber to remain at approximately 1/2-in. above the top row of quartz sleeves.

The ballast enclosures are mounted on top of the disinfection chambers and contain ballast required to transform incoming power to the power levels required to operate the UV lamps. LED assemblies and running time meters are also located on the ballast enclosures.

FACILITY OPERATIONS

UV System Control

It is noted that Sanford's UV disinfection system has never been brought on-line for any extended period of time because no fecal coliforms are being detected in the discharge from the plant's effluent filters to the UV system. However, when in use, the efficiency of the UV disinfection process is dependent upon the

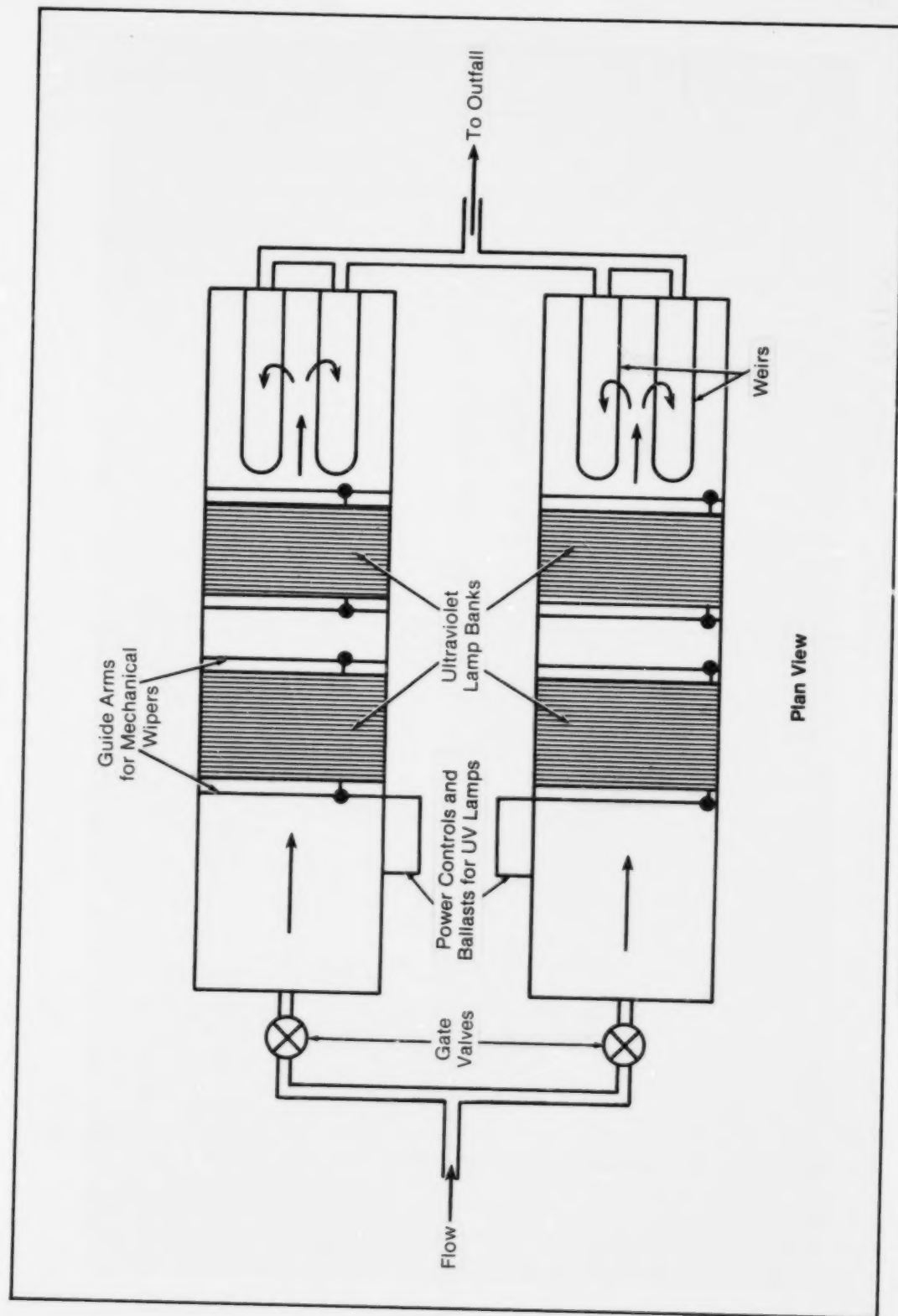


FIGURE 54 ULTRAVIOLET DISINFECTION SYSTEM

intensity of the UV source, the extent to which the UV radiation penetrates the water, and the contact time. Suspended matter, dissolved organic material, and the water itself can also affect this efficiency since they, as well as the target bacteria, can absorb the radiation. The disinfection system is designed to operate with a maximum turbidity of 5 jtu and a maximum suspended solids concentration of 10 mg/L.

Flow rate through the disinfection units is determined by the plant influent flow rate; however, the operator has the choice of running one or both of the disinfection units. If the total influent flow rate drops below 1,550 gpm (2.2 mgd), the operator may shut down one disinfection unit and divert all the flow through the remaining one. The UV disinfection process is also monitored by dosage meters (dosimeters).

To maintain a desired constant dosage, the lamp intensity must be increased when the flow rate increases, and reduced when the flow decreases. Alternately, the lamp intensity may be kept constant and the number of lamps in service varied to maintain dosage with changing flow rates.

The automatic Energy Management System (EMS) performs this function continuously. Information inputs to the EMS consist of water flow rate and UV light intensity. The EMS uses this information and other stored data to calculate the UV dosage. The dosage is automatically adjusted by turning on or off one of the four banks of UV lamps as needed.

Flow rate through the disinfection units is determined by the plant influent flow rate. Initially, the reference dosage is set at 30,000 micro watts-seconds per centimeter squared. The EMS automatically calculates the dosage of UV energy and compares it to the preset reference dosage. If the calculated dosage is above or below the referenced dosage by a preprogrammed amount, one or more of the four sections of UV lamps are switched on or off to bring the calculated dosage closer to the preset amount.

The amount of UV radiation transmitted through the water is sensed by an Aquafine Model S-254 UV optical sensor. The S-254 is a UV photo-optical sensing probe which is placed into the disinfection chamber to monitor the relative amount of UV intensity which has passed into and through the water as the water

flows through the chamber. The model S-254 includes a UV intensity meter mounted on the control console which visually shows the accumulated amount of germicidal short wave UV radiation which has reached the photo-optical lens of the sensor probe located on the inside wall of the disinfection chamber.

Each of the UV modules includes:

- Section failure lights which provide a visible warning should the UV energy level in any of the module's four sections drop below the permissible minimum.
- An amber "on" light which indicates when the cleaning wiper assembly is in operation.
- A blower failure light which is actuated if any of the cooling blowers fail.
- A section operation light that indicates which of the four sections are in operation at any given time.
- Section interrupt switches which allow manual shut-down and re-start of any section.
- Program override switches which allow interruption of the automatic section operating plan, as selected by the computerized EMS.
- A signal converter meter to verify that the intensity meter is providing proper signal.
- A dosage meter which displays effective UV germicidal dosage at the 254 nm waveband. The UV dosage is computed in the EMS by combining the flow rate through the equipment and the UV intensity passing from the UV lamps, through the protective quartz sleeves, and through the wastewater.
- Relative intensity meters which monitor the intensity of the reference UV lamp in each of the four sections. The output of the four intensity meters in each module is integrated by the EMS and forms part of the formula for determining UV dosage.
- A reference dosage thumbwheel switch to set the desired UV dosage.

Start-Up and Operational Problems

Initially, problems were encountered with the weir control system used to maintain the water level within the unit at a proper level. It was determined that there was not enough variation between the high and low level contact points, which subsequently caused the relays to burn out. The manufacturer reset the water level sensors and replaced the instantaneous relays with time delay relays.

Another difficulty experienced during start-up involved the flow proportional aspect of the UV dosage control strategy. A BIF venturi flow tube is provided to measure the influent flow rate to each disinfection unit. The UV system is energized only upon a flow signal in excess of 400 gpm transmitted from the flow tube (differential pressure cell) to the EMS program. During the initial start-up, when there was no actual flow going through the units, the flow meters still transmitted a signal to the UV program, thus turning on the units when there was no flow going through them. The problem appears to be air entrainment within the signal lines from the venturi to the differential pressure cell; however, this has not been confirmed by the manufacturer. The flow meters require frequent calibration to ensure operability, and the air must be drained daily from the signal lines. Also, since the flow signal must be in excess of 400 gpm to energize the UV units, the initial flow is not disinfected.

Another problem encountered involved the circuit boards for the UV lamps and ballasts. All the circuit boards had to be replaced because they burned out.

Foam generation, which has been attributed to textile wastes, has occurred in the UV chambers. This foam generation tends to form a "scum" on the quartz tubes within the UV disinfection unit. If one of the UV units is taken off-line for any reason, the disinfection chamber must be drained and manually washed down to remove any film left on the tubes. If this is not done, the scum hardens on the tubes, and when the unit is placed back into operation the wiper tends to "hang up" on the tubes and push them out of their housings.

Operations and Maintenance Staff

Plant personnel seemed very interested in the operation of the UV disinfection system. The operators' understanding of the process seemed to be more mechanical than technical in nature; however, they were not intimidated by the process instrumentation or the EMS program.

MAINTENANCE

A routine maintenance schedule has been established for the UV system; however, the process is currently not on-line because no fecal coliforms are being detected in the effluent filter discharge to the UV unit. The following periodic maintenance checks are listed in the plant's O&M manual and the UV vendor manual:

- Replacement of UV Lamps After 8,000 Hours of Operation: Running time meters are supplied for each of the four sections within each of the disinfection modules. All UV lamps in each section will have the same number of operating hours unless early lamp failure has required the replacement of specific UV lamps earlier. If this occurs, a separate written record of such early replacement, noting the lamp placement number, is maintained by the plant operator.
- Gear Head: The gear head on the cleaning mechanism's electrical drive motors requires lubrication every three months. There are two such assemblies located in each module, and lubrication instructions are provided both with the equipment preventive maintenance schedule and the manufacturer's data sheet. There are no other routine maintenance items with this equipment. The gear motor for the drive mechanism is permanently lubricated and the cleaning mechanism is self-lubricating.
- Cleaning Wiper Assemblies: Each quartz sleeve is cleaned with a series of cleaning wiper assemblies. These wiper assemblies are contained in carrier plates and transverse across the quartz sleeves in a carrier assembly driven by a lead screw. Each quartz sleeve has two cleaning wiper assemblies. It is anticipated that the ethylene propylene wipers themselves will have an operational life of 12 months.
- Water-Level Baffle Motors and Chain Transmission Assembly: Check chain tension periodically and adjust as required. The assembly speed is very slow, so removal of chain back-lash or sag is important for proper operation.

Spare parts included with the system include:

- UV lamps - 26
- Quartz sleeves - 26
- Ballasts - 13
- O-rings - 102

OPERATIONS AND MAINTENANCE COSTS

Operations and maintenance costs could not be formulated because the system is currently not on-line.

HATFIELD WASTEWATER TREATMENT PLANT HATFIELD, ARKANSAS

GENERAL

Hatfield is located in west central Arkansas, approximately 165 miles west of Little Rock (see Figure 55). The plant was constructed in 1979 at a total construction cost of approximately 1.5 million dollars. The treatment plant began operation in March 1980 at a flow of 32,000 gallons/day (70,000 gallons/day design). The treatment system consists of the following sequential processes: a primary lagoon, polishing pond, over-land flow, and UV disinfection. A schematic representation of the treatment plant's layout is shown in Figure 56. The plant's final effluent is discharged into Joshland Creek. The plant was visited on 10 May 1982.

The UV disinfection system has been down since May 1981 due to system failure and the inability to obtain replacement bulbs. The plant operates under NPDES Permit No. AR0035483; the permit limits are summarized in Table 31. Typical effluent quality is 5 to 20 mg/L BOD₅, 0 to 40 mg/L TSS, and 20 to 120 mpn fecal coliforms per 100 ml.

Table 31

NPDES Discharge Limitations Hatfield Wastewater Treatment Plant Hatfield, Arkansas

Parameter	Discharge Limit
BOD ₅ , Monthly Average	15 mg/L
TSS, Monthly Average	10 mg/L
Monthly Maximum	20 mg/L
Fecal Coliform, mpn Median	20/100 ml
Maximum Average Flow Rate	70,000 gpd

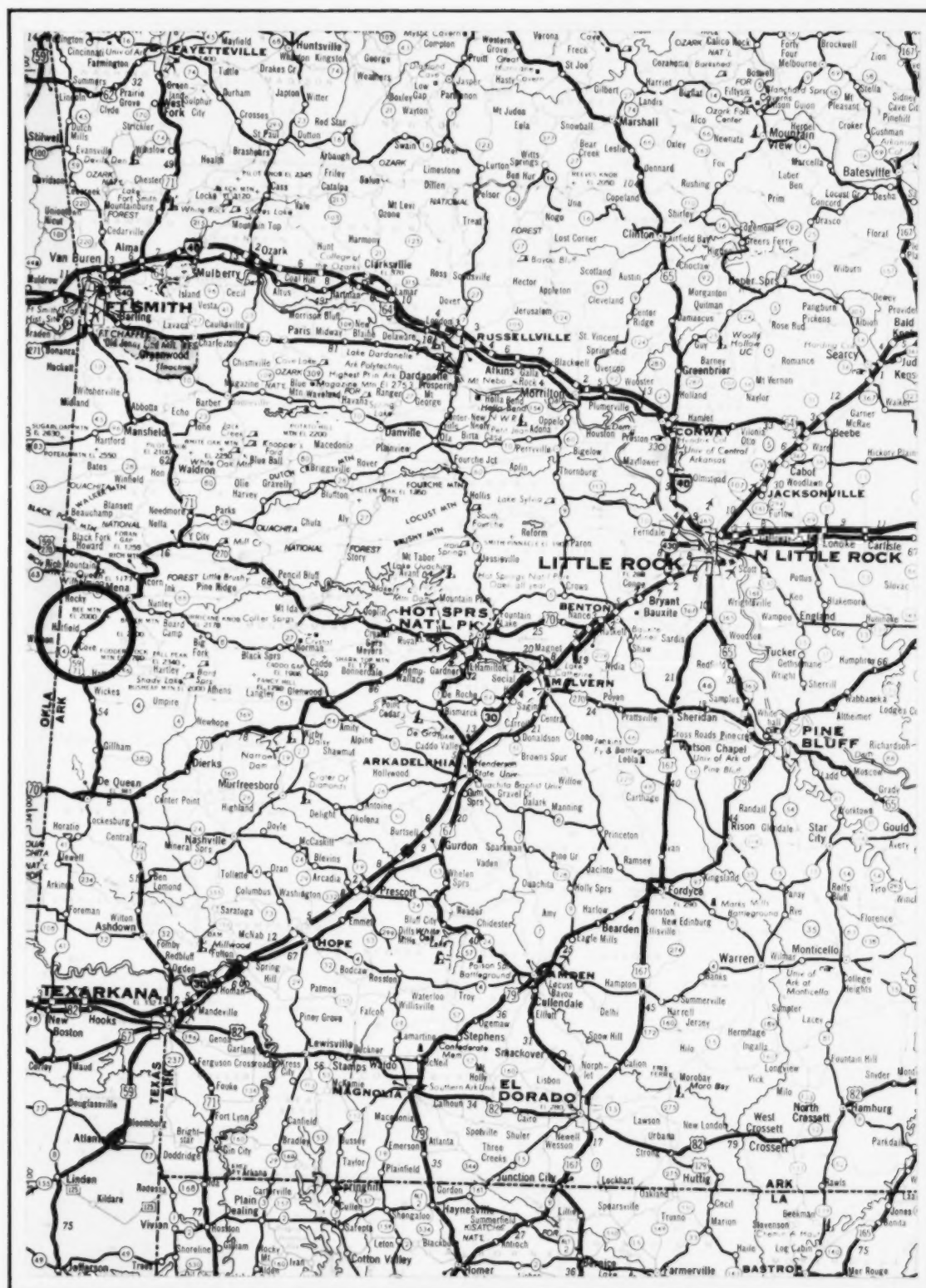


FIGURE 55 PLANT LOCATION MAP

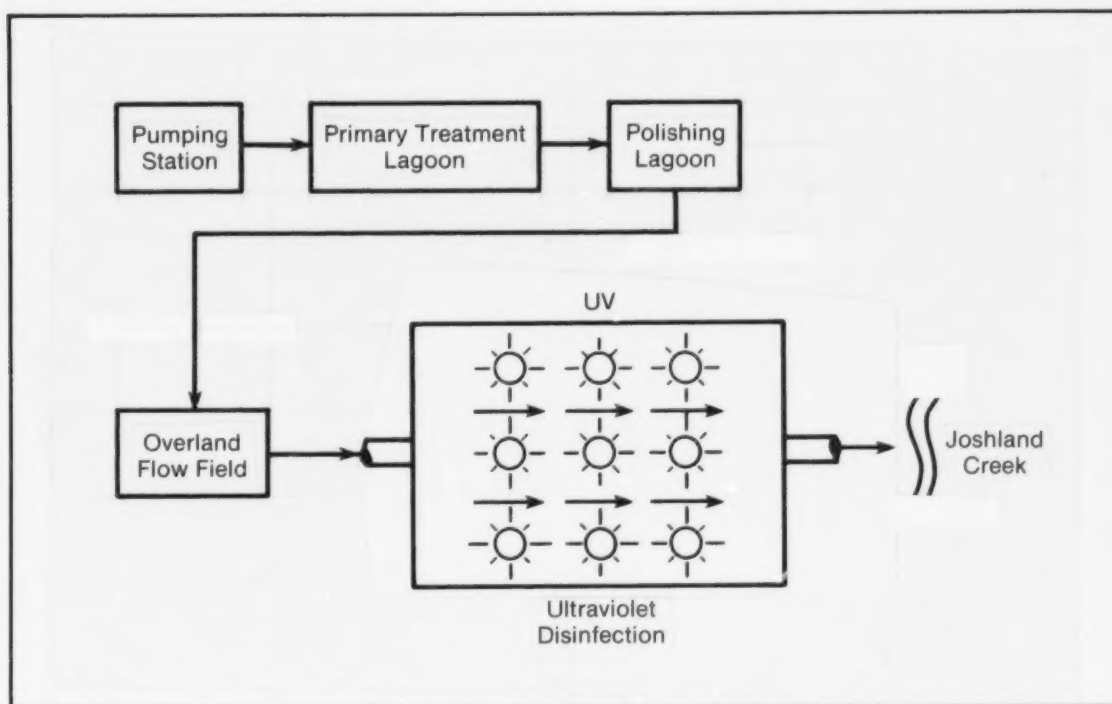


FIGURE 56 PLANT FLOW DIAGRAM

UV SYSTEM DESCRIPTION

The Hatfield Wastewater Treatment Plant utilizes a Model G-500 UV disinfection unit manufactured by Ultraviolet Technology, Inc. (now named ENERCO). The disinfection system uses teflon piping to carry wastewater flows. The units' UV lamps are situated external to the teflon tubes. The disinfection system utilizes low-pressure mercury lamps that generate UV radiation with a wavelength in the region of 254 nm.

The germicidal lamps are a constant source of UV energy; however, their energy level decreases with increasing lamp operating time. The normal decrease in UV energy is about 40 percent after 7,200 hours of operation, at which time the manufacturer recommends the lamps be replaced. The wastewater flows through teflon tubes, which are arranged in parallel. A schematic representation of the disinfection chamber is shown in Figure 57. The advantages of using teflon tubes, as claimed by the manufacturer, are as follows:

- Teflon has excellent UV light-transmittance properties, although less than quartz.
- Teflon is chemically inert and is not attacked by substances typically present in water and wastewater.
- Teflon is non-wetting and generally does not get fouled by substances present in water. If fouling occurs, a simple detergent or chemical cleaning can be applied to remove deposits.
- Teflon is virtually unaffected by UV energy and temperature up to 400°F.

The UV disinfection chamber houses 48 General Electric Model GP30T8 UV bulbs. The bulbs are arranged in 3 banks, 31 in. long, that run the length of the disinfection chamber. A cross-sectional view of the disinfection chamber and a lamp bank are shown in Figure 58. The lamp end-caps are made of nonconductive epoxy resin. Each UV lamp is rated at 30-watts input wattage and 8.7 UV output wattage.

The disinfection system is designed for a 30-second detention time at 70,000 gpd. At times no disinfection is required at the plant because the overland treatment system has zero discharge. When flow does enter the disinfection chamber, it is sensed by a

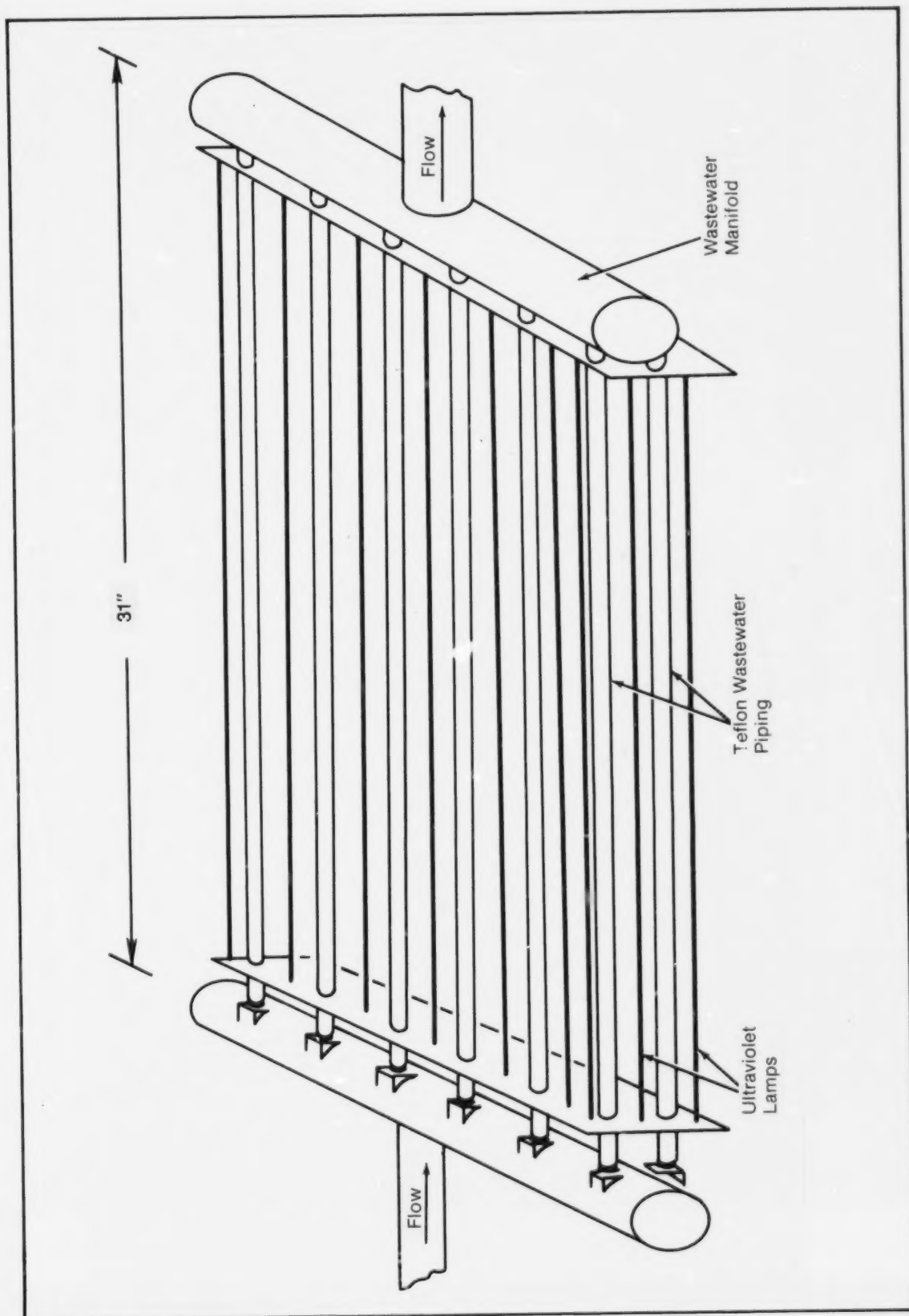


FIGURE 57 ISOMETRIC VIEW OF UV
DISINFECTION CHAMBER

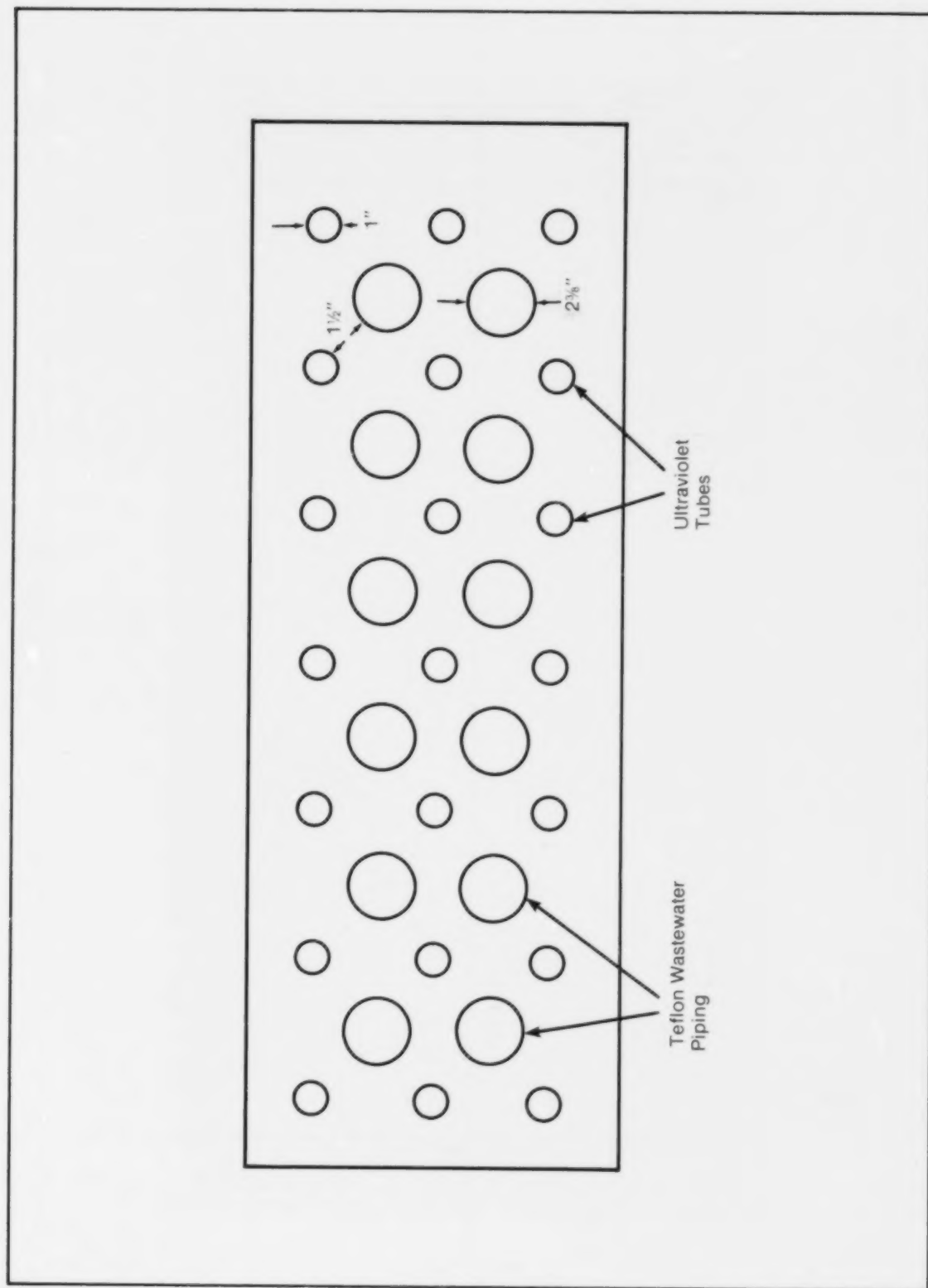


FIGURE 58 END VIEW OF UV

float-actuated switch that turns on the power supply to the UV lamps. Constant voltage is supplied to the lamps, regardless of the quantity or quality of the wastewater flow. There is no mechanical cleaning mechanism; however, the manufacturer recommends simple detergent or chemical cleaning if the teflon piping becomes fouled.

The entire disinfection system is housed in a welded steel box with three hinged-top covers. On the top and bottom of the lamp banks, white aluminum reflectors help retain the UV rays. Safety switches are installed on each of the three metal covers so that if any one of the covers is opened, the power supply to the entire disinfection system is shut off. In addition, each of the three metal covers can be locked.

The system's design parameters are listed in Table 32.

Table 32

UV System Design Parameters
Hatfield, Arkansas

UV Technologies Model G-500	
1. Fluid Flow Rate	- 500 gpm at less than 1 ft pressure drop
2. Power Requirement	- 120-volts, 60-Hz, single-phase 25.63 amps
3. Contact Time	- .3 seconds
4. Total Germicidal Output	- 416 UV watts at 253.7 nm

FACILITY OPERATIONS

UV System Control

The Hatfield UV disinfection system is designed for an on-off operating cycle. When flow sensors located at the disinfection

system are actuated, all the UV lamps are turned on to full power. Presently, no provisions exist for extinguishing individual banks of lamps or varying the voltage to the lamps.

Start-Up and Operational Problems

The Hatfield UV system was in operation for approximately one year and three months (March 1980 to May 1981). The system has been down for approximately one year.

The original disinfection system designed for the plant included a concrete chlorine contact chamber. However, after construction of the contact tank was completed, a decision was made to switch to UV disinfection. Therefore, the UV disinfection chamber was sized to fit inside the already-constructed chlorine contact tank. Two sump pumps were placed in the bottom of the concrete tank to pump out rainwater. However, the sump pumps malfunctioned, and high water levels in the concrete tank caused short-circuiting of the power supply to the UV equipment. To date, this problem has not been corrected.

A second problem encountered at the plant concerned the location of the flow actuated on-off switch for the UV system. This float switch was installed downstream of a weir structure and was subjected to turbulences which caused rapid chattering of the power switch. During low flow conditions, the power to the UV system was being rapidly turned on and off, causing premature bulb failure. A solution to this problem would be to move the float-actuated switch to the upstream side of the weir, hence eliminating switch chattering.

A final deficiency noted during the plant visit was the fact that the disinfection teflon tubes were not kept full of water during and in between plant flow periods. This allowed for the formation of air pockets inside all of the teflon tubes and appeared to accelerate biological growth on the inside of the tubes. A possible solution to this problem would be to slope the disinfection chamber such that the outlet pipe is slightly higher than the inlet pipe.

Operations and Maintenance Staff

Although the Hatfield plant has only one operator who acts as supervisor, operator, and maintenance staff, he is fully qualified and able to handle these duties. The plant operator's ability to adequately conduct all of the duties required of the

treatment plant is reflected in the excellent performance of the plant. In addition, the operator displayed a good technical understanding of the UV disinfection system.

MAINTENANCE

When used, little maintenance was required for the Hatfield UV disinfection system. The maintenance program includes replacing bulbs and ballasts, and periodically cleaning the inner surfaces of the teflon piping. Periodic checks should also be made of the flow-actuated UV system on-off switch and the on-off switch which is actuated upon opening of the unit's covers. For cleaning the inner surfaces of the disinfection piping, the manufacturer indicates that a simple detergent or chemical cleaner may be used. However, actual procedures are not given and the plant operator has not felt the need to actually clean the unit to date.

Considerable problems have been experienced in attempting to get replacement bulbs for the UV system. A delay of approximately one year was experienced between the time the bulbs were ordered and the time they were finally delivered.

OPERATIONS AND MAINTENANCE COST

A breakdown of operation and maintenance costs for the Hatfield Wastewater Treatment Plant, in terms of cents/UV input kilowatt hours, is given in Table 33. It is noted that electric usage could not be measured since the system was not on-line and, therefore, utility costs were estimated based on the manufacturer's rated UV input wattage for the system. Operation and maintenance labor costs represent the plant operator's best estimates for these respective levels of activity. The UV disinfection system's insurance cost was calculated by taking the total cost of the plant's insurance policy and multiplying it by the ratio of the fixed capital investment for the UV system to the total fixed capital cost of the entire plant.

Table 33

Hatfield Wastewater Treatment Plant UV System Cost Sheet

FCI = \$16,250

Cost Item	Cost ¢/UV Output kwh
<u>Operating Cost</u>	
Electric Power	31
Operating Labor (.050 MY)** (including repair and supervision labor)	4
Repair Labor (.228 MY)	18
Supervision (0.046 MY)	<u>4</u>
Total Operating Cost	57
<u>Overhead Cost</u>	
Insurance (0.15% FCI)*	3
Amortization (7% at 20 years)	<u>168</u>
Total Overhead Cost	169
TOTAL UV COST, ¢/Rated UV Output (kwh)	226

FCI, Fixed Capital Investment
MY, Man Year (2,080 hrs)

*Actual numbers are unavailable and these percentages were taken from Opatken, E.J. EPA-600/9-79-018, 1979.

**Assumes only 6 hours of operation per day (2,190 hours per year) and 911 U.V. output kwh per year.